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Summary of Investigations 1987, Saskatchewan Geological Survey

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Foreword

The Summary of Investigations 1987 covers almost all of the geoscientific work carried out by staff of the Saskatchewan Department of Energy and Mines, and includes papers from the Geological Survey of Canada, Saskatchewan Research Council and the Universities of Saskatchewan, Regina, Waterloo, Exeter, Kansas, Pittsburgh and California. The contributions of these institutions is gratefully acknowledged, as are the efforts of the less visible contributers who undertook the extensive editing and production duties.

As part of the general downsizing of the Public Service in May 1987, the Director of the Saskatchewan Geological Survey, Dr. James E. Christopher, elected to take early retirement and the position was eliminated. This resulted in re-organization of the former Geological Survey Branch into three smaller branches. The name "Saskatchewan Geological Survey", although removed from the organization chart, is retained to identify geoscientific activities carried out by staff of the Geology and Mines Division. It is my pleasure at this time to acknowledge the leadership that Jim Christopher provided to the Survey for many years and for his valuable contributions to the understanding of the geology and economic potential of the sedimentary strata of the province. Inclusion of a "post-retirement" paper by Dr. Christopher in this report is a welcome indication that his contributions to Saskatchewan geology will continue.

Despite a 40 percent decrease in the Survey's operational budget, most projects funded under the Canada-Saskatchewan Mineral Development Agreement were continued. By prudent use of available funds and leveraged contracts, the program focus on gold in the La Ronge - Southend - Flin Flon triangle was broadened to include projects in the Uranium City and Pine Channel areas, as well as a return to uranium studies.

L.S. Beck
Executive Director
Geology and Mines Division

October, 1987

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Note: Asterisked reports have an accompanying map. A list of accompanying map titles can be found on the inside front cover of the map package.

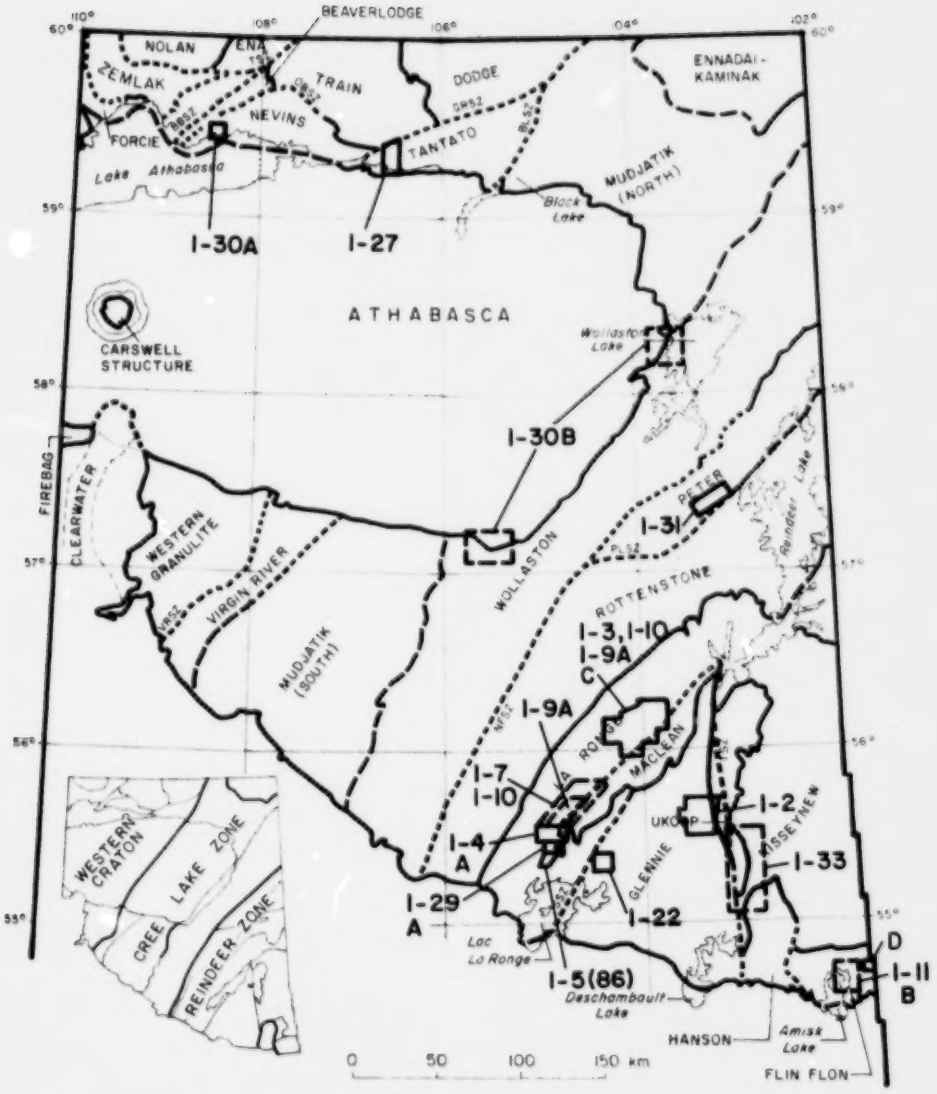


Figure 1 - Location of projects or reports in hand 1987-88 (excluding compilation maps and GSC projects). Numbers or letters on map refer to letters or Mineral Development Agreement (MDA) numbers opposite. The map base shows in abbreviated form the distribution of the main lithostructural domains in northern Saskatchewan.

Highlights of the Northern Geoscience Program 1987-88

by R. Macdonald and T.I.I. Sibbald

The geoscience program in northern Saskatchewan has continued this year to focus largely on the gold exploration play which has now reached new heights of activity. Gold is not all, however, and conscious of the mineral industry's long-term stake in uranium as well as the growing exploration interest in the platinum group metals and rare earth elements, some attention has also been given to the geological environment of these elements.

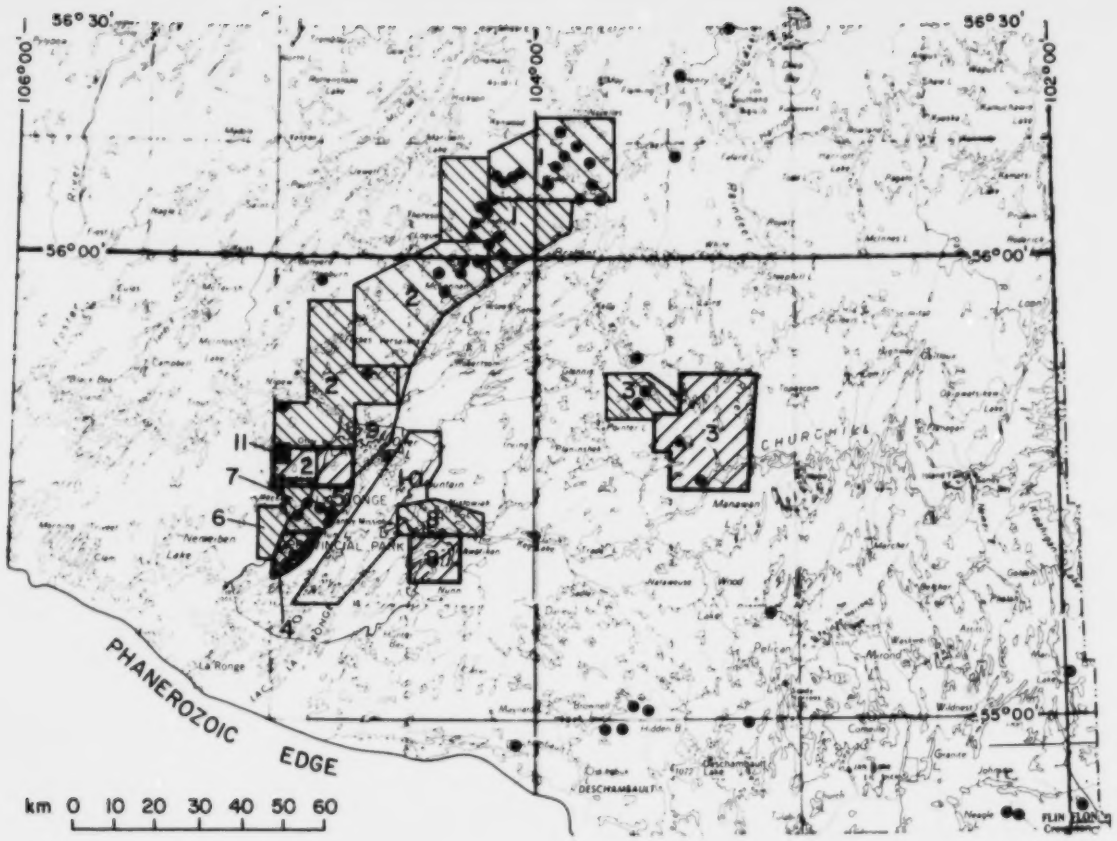
Although the increasing pace of mineral exploration in the north has coincided with cutbacks in government expenditures leading to a reduction in the bedrock remapping program, the budget has continued to be stretched out by means of small joint-venture projects with university and other personnel.

As in previous years, there are contributions to this publication from the Saskatchewan Research Council. The majority of the projects reported in this publication have, however, been generated wholly or in part through the Canada-Saskatchewan Mineral Development Agreement 1984-89, now in its fourth year. Under the terms of this agreement the province and federal government mount individual but coordinated geoscience programs on a 50:50 funded parallel-delivery basis.

The provincial component of the agreement has been mainly in the form of bedrock geological remapping at 1:20,000 scale (Fig. 2), compilations (Fig. 3), and supporting lithogeochemical, isotopic, geochronological and mineral deposit studies, packaged in what is known as the Gold Belt Geology Program. The federal part of the program, undertaken by the Geological Survey of Canada, has mainly comprised regional airborne magnetic gradiometer and regional lake sediment geochemical surveys as well as some ground geological investigations. The gradiometer surveys were flown in 1986-87 over the area lying between Flin Flon and Hanson Lake, covering the Shield edge and a large part of the terrain immediately to the south underlain by Lower Paleozoic rocks; these are due for release on open file by the GSC in preliminary form this year, and in final form in 1988.

MDA No.	Proj. No.	Area/ Short Title	Project Leader	Notes
Gold Belt Geology Program:				
1-2	8722	Bedrock Mapping, Carruthers-Uskik Lakes	G.D. Delaney	1 *
1-3	8711	Trace Element Chemistry Waddy-Windrum	C.T. Harper	6 *
1-4	8712	Bedrock Mapping, Bing Lake	D.J. Thomas	1 *
1-5 (86)	8606	Bedrock Mapping, Sulphide Lake	T.I.I. Sibbald	6 *
1-27	8701	Bedrock Mapping, Pine Channel	W.L. Slimmon & R. Macdonald	1 *
1-31	8733	Bedrock Mapping, Campbell River	D.G. MacDougall	1 *
1-7	8708	Geochronology: K-Ar & Rb-Sr	K. Bell & M. Bikerman	1,3
1-8	8704	Geochronology: U-Pb Zircon & Nd-Sm	M.E. Bickford et al.	1,2,3,4
1-10	8721	Geochemistry: Central Metavolcanic Belt	B.R. Watters	3,4
1-11	8702	Geochemistry: Flin Flon REE	G.R. Parslow	3
1-18	8705	Mineralized Core Collection	A.J. Gracie	1,2
1-22	8724	Iskwatikan Geology & Geochronology	J.R. Chiarenzelli & J.F. Lewry	4 *
1-33	8736	P-T Studies, Kisseynew Domain	D. Perkins	4
1-29	8731	Gold Metallogeny, Sulphide Lake	D.C. Armstrong & G.R. Parslow	3
1-30A	8732	Uranium Studies, Nicholson Bay	P.W. Peiris & G.R. Parslow	3
1-30B	8735	Uranium Studies, Unconformity Geochemistry	G.R. Parslow	4
Other Northern Studies:				
	A	Bassett Lake Mafic Intrusion	I. Graham et al. (U. of Regina)	1,5
	B	Quaternary Geology: East Amisk	J.E. Campbell (SRC)	1,5 *
	C	Mineral Deposit Studies, Waddy & Goldfields	D. Quirt (SRC)	1,5
	D	Metallogenic Studies, Rio Gold Mine	M. Mellinger & J.G. Pearson	4,5

1 Field component in 1987
2 Project covered wide area (not shown on map)
3 Contract project in 1987
4 Joint venture with SEM in 1987
5 Externally contributed report
6 Office follow-up or write-up in 1987
* Geological or geochemical map(s) in accompanying package



1) Gold Belt Geology Program of the MDA

A) Investigations in the Central Metavolcanic Belt (CMB)

Bedrock Mapping - D.J. Thomas remapped the Bing Lake area in the southern part of the belt this summer, bridging the gap with the Sulphide - Mackay Lakes area mapped by others last year. Rocks of the CMB and MacLean Lake Belt interfinger in this area, and may be stratigraphically equivalent. McLennan Group meta-arkoses overlie the CMB in a major disconformity on the western side of the Haugen Lake Synform. The major plutons in this part of the CMB at least appear to be pre-McLennan Group. Complex crescent-shaped fold interference structures probably indicate deeper crustal levels than farther north in the belt.

Exploration Targets: Shear zones, particularly those cutting plutons, are considered to provide the most favourable structural target for gold mineralization in the area. Major shear zones in the west contain gash quartz veins, brecciation with quartz-flooding, and sulphides. Potential

Figure 2 - Progress of bedrock remapping at 1:20,000 scale or better in the La Ronge and Glennie Lake Domains. Dots represent approximate locations of known gold occurrences or mines.

Gold Belt Geology Program:

Remapping in 1984 and 1985

Remapping in 1986

Remapping in 1986, published here

Remapping in 1987

Geologists:

1, C.T. Harper; 2, D.J. Thomas; 3, G.D. Delaney; 4, T.I.I. Sibbald; 5, W.L. Slimmon; 6, M.W. Thomas; 7, J.F. Lewry; 8, J.R. Chiarenzelli; 9, A. Abraham; 10, J.F. Lewry (1981); 11, I. Graham

environments for stratabound gold mineralization occur in 1) the transitional assemblage between the CMB and the MacLean Lake Belt, 2) copper-rich "trachytic" intermediate flows and epiclastic metasediments in the Milner - Cathro Lakes area, and 3) gossanous calc-silicate and amphibolitic rocks in the eastern part of the area. Some metasediments in the McLennan Group are enriched in heavy minerals, and may provide paleoplacer environments for REE and gold.

Lithogeochemical Studies - B.R. Watters (University of Regina) continues work in the CMB in collaboration with C.T. Harper and D.J. Thomas. Current studies include major and trace element analyses of the plutons in the Esmay - Onipoowuk Lakes area, southern part of the CMB and, secondly, a detailed geochemical and petrographic study of the Brindson Lake Pluton. The southern plutons are generally calc-alkaline, similarly to the other plutons in the CMB. The Brindson Lake Pluton is a composite or zoned batholith of greater complexity than the Star Lake Pluton to the south.

Trace Element Geochemistry - C.T. Harper has plotted geochemical analyses from the Waddy - Windrum Lakes area to determine background concentrations for volcanics and intrusives with special emphasis on gold. A map is included in the package to this report. The volcanic rocks typically contain twice as much gold as their intrusive equivalents. Several areas of anomalous gold concentration not related to known gold occurrences have been identified as potential exploration targets.

Kenwood - Nistoassini Pluton Study - D. Quirt (SRC) in collaboration with C.T. Harper has commenced a geochemical study of the Kenwood and Nistoassini Lake Plutons.

Gold Studies, Sulphide - PAP Lakes - An investigation of gold deposits in the Sulphide - PAP Lakes area was initiated by D.C. Armstrong (University of Aston) and G.R. Parslow (University of Regina). Detailed geological mapping and core logging have been undertaken in the vicinity of the stratabound Studer A, B and C zones to evaluate host lithologies and controls of mineralization. An investigation was also begun of the shear zone-controlled PAP mineralization. In conjunction, bedrock sampling will provide material for lithogeochemical, fluid inclusion, stable isotope and geochronological studies.

B) Investigations in the Glennie Lake Domain

Bedrock Mapping - G.D. Delaney extended remapping southeast from Laonil Lake into the Carruthers - Uskik Lakes area this summer, along the greenstone belts towards the Reindeer River. The Glennie Lake Domain has high potential for gold exploration, and this work is part of a larger plan to remap the greenstone belts in the domain. The Carruthers - Uskik Lakes area contains two main supracrustal assemblages: 1) the Ourom Lake Meta-arkoses which are extensional basin deposits produced by a deep-seated fault system presently marked by the Tabbernor Lake Fault, and 2) the younger Pine Lake Metavolcanics, which are mostly fine grained and regarded as arc-proximal basin deposits.

Exploration Targets: The most important gold exploration target in the Carruthers - Uskik Lakes area is considered to be syngenetic stratiform gold/silver hosted in the volcaniclastic rocks. Anomalous concentrations of gold are also associated with copper showings in fracture/fault zones in a variety of rock types.

Iskwatikan Lake Area - J.R. Chiarenzelli continued his mapping and geochronological project, this year covering the Iskwatikan Lake area. This work is part of a Ph.D study at the University of Kansas. An Archean U/Pb zircon date was obtained during the winter from the area. This summer an apparent domal Archean inlier has been mapped out which is separated from structurally overlying supracrustal rocks by a major detachment surface. These findings will have important implications for the structure and tectonics of the Glennie Lake Domain.

C) Pine Channel Study

The Pine Channel, on the north shore of Lake Athabasca east of Fond-du-Lac, has been known for many years to host gold deposits, and is the scene of recent exploration interest. This summer W.L. Slimmon with assistance from R. Macdonald remapped a strip of country north from the gold deposits. A northern assemblage is interpreted as variably mylonitized plutonic rocks with minor supracrustals. The southern assemblage, which contains all the gold showings, comprises hypersthene-bearing garnetiferous felsic gneisses, pyribolites and amphibolites, and is interpreted as derived from volcanic arc greywackes and volcaniclastic/volcanic rocks.

Most gold showings in the area are associated with localized regionally crosscutting sulphide-bearing quartz-filled fractures and shears which may be related to regionally conformable faults and shears.

D) Investigations in the Peter Lake Domain

Bedrock Mapping - D.G. MacDougall, working in the Campbell River area, has traced the Campbell River Group farther southwest than previously mapped, and has identified the contact with gneisses of the Peter Lake Complex as a possible

overthrust unconformity. Way-up structures indicate that the succession is locally uninverted. Late syenogranitic plutons are postorogenic and concentrically zoned. Undersaturated syenites in the northeast contain monazite and may be a source of REE.

E) Southeastern Shield

Geochemistry - G.R. Parslow (University of Regina) is re-analyzing old samples from the East Amisk Lake area for REE. Preliminary REE patterns appear to confirm the presence of oceanic-type basalts in the East Amisk Lake area. The relation to known arc-type basalts in the Flin Flon area has yet to be determined.

F) Bedrock Compilation and Data

The Fond-du-Lac preliminary 1:250,000 bedrock geology compilation map is included in this report. Brief investigations this summer helped to elucidate the nature of the junction between the Nevins Lake, Tantato and Dodge Domains. The final coloured versions of the Pelican Narrows and Amisk Lake 1:250,000-scale map sheets are planned for release this winter (Fig. 3).

Although not presented in this report, the following Precambrian data files are being updated on microcomputer and may be consulted in the Regina office: Sample Index, Geochronological Database, Bibliography and Lexicon.

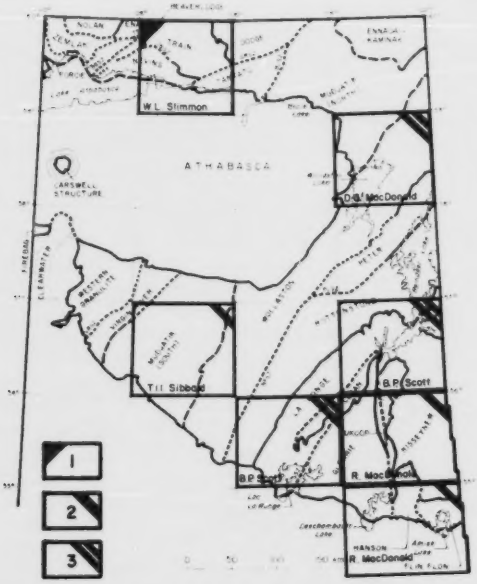


Figure 3 - Location of 1:250,000 scale compilation maps which were published or in progress in 1987-88. Legend key: 1, Compilation Bedrock Geology preliminary black line version published; 2, Compilation Bedrock Geology final colour version expected to be published in winter of 1987; 3, Compilation Metallogenic map in progress.

G) Uranium Studies

Two projects were initiated, both under contract to the University of Regina.

P.W. Peiras and G.R. Parslow collected bedrock samples from the Nicholson Bay zones of uranium-gold-PGM mineralization currently under active exploration. Petrographic and geochemical studies are expected to characterize the mineralization and associated alteration.

G.R. Parslow is examining the geochemistry of the "basement" felsic gneisses where they immediately underlie the presumed Archean-Aphebian unconformity. Major and trace element analyses, and petrographic examinations are expected to determine whether paleoweathering is present in the basement gneisses.

H) REE Element Review

In response to the growing demand for information on the REE in northern Saskatchewan, C.T. Harper includes here a review and classification of the known REE and yttrium occurrences in Saskatchewan.

I) Geochronological, Isotopic and P-T Studies

Rb-Sr and K-Ar - Further collecting of material for K-Ar studies took place this summer in the CMB (M. Bikerman, University of Pittsburgh), with a view to dating later events associated with the gold mineralization.

U/Pb Zircon and Nd/Sm - The joint venture with the University of Kansas was restricted this year by the termination of U.S. funding. Nevertheless some new and refined results have emerged, notably:

Mudjatik Domain:	
Charnockitic rock, Dipper Lake	ca. 2000 Ma
Gneiss, Dipper lake	ca. 1889-2003 Ma
Granitic gneiss, Johnson River Inlier	2186±46 Ma
Peter Lake Domain:	
Gabbro pegmatite	ca. 1908 Ma
Hanson Lake Block:	
Granodiorite, Bertram Bay	1844±12 Ma
Jan Lake Granite suite	1773±9 Ma
Greater Beaverlodge Area:	
Stephens Lake Granite	ca. 2410 Ma

P-T Studies - Dexter Perkins (University of North Dakota) collected samples from the western part of the Kisseynew Domain this summer as a preliminary to P-T mineral studies.

J) Mineral Data and Compilation Maps

Under the Mineralized Core Collection project, 1172 m of new core has been collected this year. Existing mineralized core representative of several base and precious metal deposits in the Flin Flon area, totalling 4325 m, were moved from the Creighton office to La Ronge.

The Saskatchewan Mineral Deposits Index is now up to date in respect of information retrieved from nonconfidential assessment records, with the exception of NTS area 74N.

Three new 1:250,000 scale metallogenic maps (64D, 64L and 73P) are expected to be ready for publication by year end.

2) MDA Geoscience Program: GSC Studies

This year K.E. Ashton for the GSC completed the remapping of the southern part of the Kisseynew Gneiss terrain, and have become thoroughly involved in the "Kisseynew Controversy" as well as the Hanson Lake Block problem.

The GSC studies into structures associated with gold mineralization in the Star Lake have been extended into the Tower Lake area, and a regional summary of late shear structures for the northern part of the Central Metavolcanic Belt is included in this report.

Larry Hulbert's contribution on investigations into mafic-ultramafic rocks and platinum group mineralization in province is timely in view of interest in PGM minerals, particularly those in the Goldfields/Beaverlodge area north of Lake Athabasca where spectacular preliminary metal values have been obtained.

3) Other Northern Studies

The Saskatchewan Research Council has provided reports on Quaternary geology (mapping by Janet Campbell on the East Amisk area), the metallogeny of the Rio Mine, Flin Flon area (M. Mellinger and J.G. Pearson), and image analysis techniques (M. Mellinger).

Colin Dunn's report describes biogeochemical studies of the Rottenstone Lake area (platinum group metals), Koliniak Lake, Central Metavolcanic Belt (phenomenal values reported for gold), and Star Lake (integration of multi-element biogeochemical data with remote-sensing data).

GOLD BELT GEOLOGY PROGRAM (MINERAL DEVELOPMENT AGREEMENT 1984-89)

Project 8722

Bedrock Geological Mapping, Carruthers - Uskik Lakes Area (Part of NTS 63M-11 and -12)

by G.D. Delaney

Delaney, G.D. (1987): Bedrock geological mapping, Carruthers - Uskik Lakes area (part of NTS 63M-11 and -12); in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

Approximately 500 km^2 were mapped at a scale of 1:20,000 in the region between Carruthers Lake and the Churchill River (NTS 63M-11 and -12). This mapping (Fig. 1) adjoins 1:20,000 scale revision mapping in the Laonil Lake area (Delaney, 1986) and includes the southern extension of the Pine Lake greenstone belt. This greenstone belt hosts several gold showings including, at Laonil Lake, the Seabee deposit which is currently being evaluated by an underground exploration program.

Field work began in late May and was completed at the end of August. A five-man crew was supplemented by two additional persons in August. Base camps were located at Carruthers, Eisler and Uskik Lakes, and supplemented by several fly camps. Camps were supplied by float-equipped aircraft based at Missinipe and Pelican Narrows. Canoes and inflatable boats were used to map shorelines of all major lakes and rivers.

In 1955, Budding and Kirkland (1956) mapped the western three-quarters of NTS sheet 63M-11 at a scale of 1:63,360. Macdonald (1975a, 1975b, 1976) mapped the eastern one third of this map-sheet area at the same scale and undertook some reconnaissance investigations in the vicinity of the Tabbernor Lake Fault. Lewry (1977) mapped NTS sheet 63M-12, also at a scale of 1:63,360. The map-area is contained in two compilation maps, an earlier synthesis by Taylor (1958) of the 1:250,000 Pelican Narrows map sheet (63M) and a recent 1:250,000 preliminary compilation by Macdonald (1981) of the Pelican Narrows and Amisk Lake map sheets.

The map-area was covered in a reconnaissance lake sediment geochemical survey completed in 1974 (Hornbrook et al., 1975, 1977, 1985)

This area is included in Geological Survey of Canada 1:63,360 scale aeromagnetic maps 4802G (63M-12) and 4803G (63M-11) and 1:250,000 scale aeromagnetic map 7764G (63M).

Project funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

GENERAL GEOLOGY

The study-area is in the north-central part of the Glennie Lake Domain, Reindeer Zone, Lower Proterozoic Trans-Hudson Orogen (Lewry, 1981a, 1987; Lewry and Collerson, in press). It has been hypothesized that the Glennie Lake Domain is one or more fragments of Proterozoic arc terrane that collided with the adjacent La Ronge Domain (Lewry, 1981a; Lewry et al., 1980; Lewry et al., 1987). These authors interpret much of the northern part of the Glennie Lake Domain to be allochthonous thrust sheets emplaced during this collisional event. Although there is good evidence to support thrust tectonics in the northwestern part of the Glennie Lake Domain (i.e., Lewry, 1981b), evidence elsewhere, including the study area, is equivocal.

The map-area is underlain by supracrustal and granitoid rocks (Fig. 1) and is cut by a segment of the major sinistral north-northwest-trending Tabbernor Lake Fault. There are two distinct supracrustal assemblages: the Pine Lake Metavolcanics and the Ourom Lake Meta-arkoses.

West of the Tabbernor Lake Fault, two north-northwest-trending belts of the Pine Lake Metavolcanics flank paragneiss and subordinate pelitic migmatite. To the east of the fault and west of the Reindeer River lies a narrow belt of metavolcanics. The metavolcanics, which have been subjected to amphibolite facies metamorphism as well as various metasomatic processes, are mostly fine-grained volcaniclastics with subordinate intermediate and mafic volcanics.

The Ourom Lake Meta-arkoses, a thick sequence of meta-arkoses that includes conglomerate and conglomeratic facies, lies mostly on the east side of the Tabbernor Lake Fault. Deposition of these sediments preceded and overlapped that of volcaniclastics of the Pine Lake Metavolcanics. Primary structures are preserved in the western part of this siliciclastic unit; an abrupt metamorphic gradient to the east tranforms these rocks into gneisses, homogeneous granitoids and migmatites.

Granitoids include a variety of early granodiorite, tonalite and quartz monzonite phases. Many of these early granitic rocks, such as the large mass of

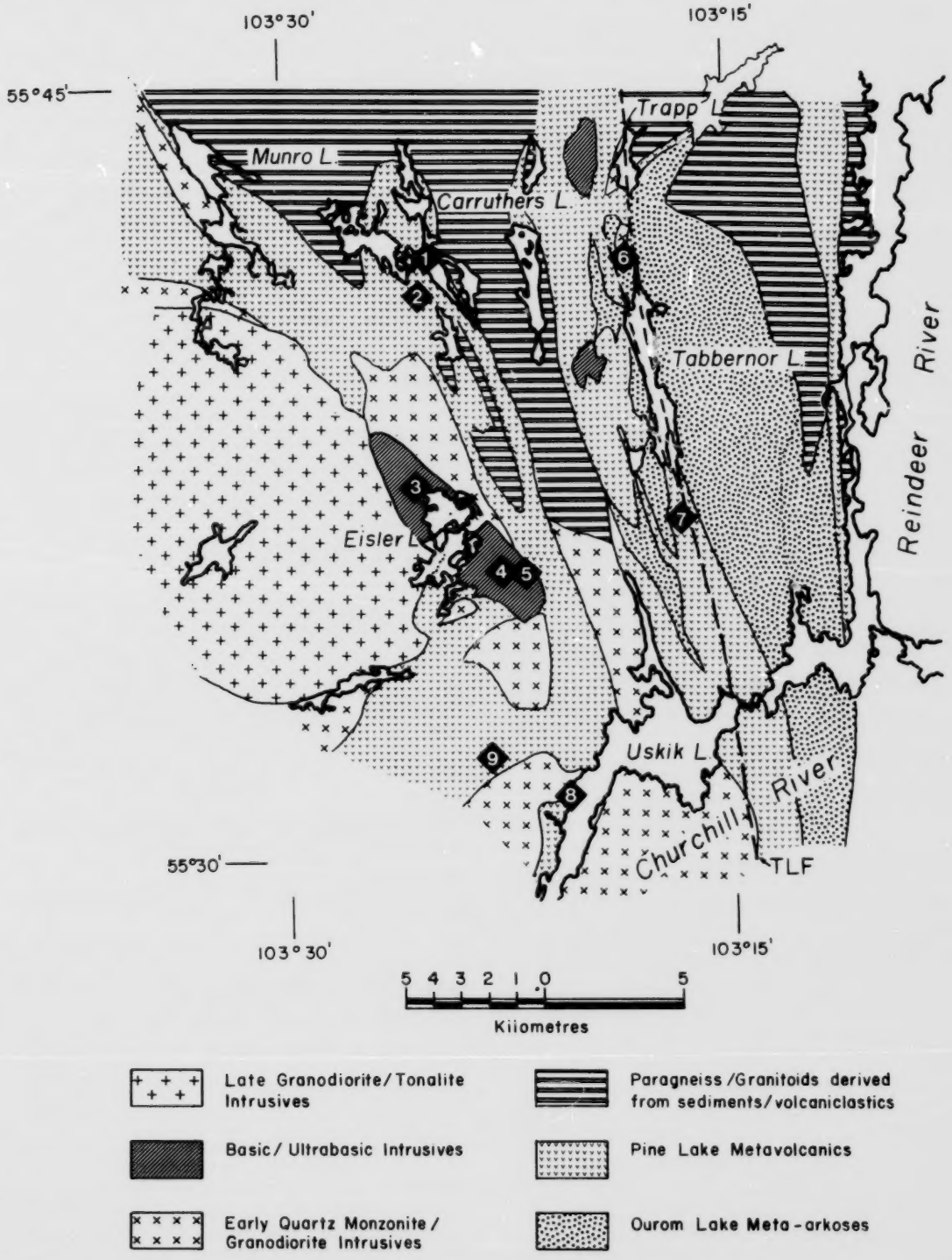


Figure 1 - Geological sketch map of the Carruthers - Uskik Lakes area. TLF, Tabbernor Lake Fault. Numbers indicate locations of mineral showings described in text: 1, Car 1; 2, Earna; 3, DD; 4, FM; 5, Small Lake showing; 6, small lake north of Tabbernor Lake; 7, small lake south of Tabbernor Lake; 8, Wek; 9, Kaz.

leucocratic granodiorite and granodiorite gneiss northeast of the Ourom Lake Meta-arkose, were probably derived from supracrustal rocks. These granitic rocks in the Eisler Lake area are cut by the gabbroic Eisler Lake Intrusive. Part of the granodioritic Wood Lake batholith intrudes the Pine Lake metavolcanics in the Uskik Lake area. The late tonalitic Eyahpaise Lake Pluton underlies the southeast. This pluton hosts a plug of younger zoned granodiorite.

Structural relationships define at least three folding episodes. Correlation with an adjacent map-area, to the northwest, suggests that these rocks were also probably subjected to an earlier event masked by subsequent processes. Although the Tabbernor Lake Fault does not appear to display significant lateral movement in the area, it marks the locus of a major depositional trough.

SUPRACRUSTAL ROCKS

Pine Lake Metavolcanics (P)

With the exception of a few small areas along the Churchill River, metamorphic processes and intense local metasomatism have generally masked primary features. Accordingly metamorphic derivatives of flow rocks were subdivided into mafic, intermediate and felsic using the criteria established by the Ontario Geological Survey (Trowell et al., 1978).

The Pine Lake Metavolcanics are exposed in three north-trending belts (Fig. 1) extending: 1) from Munro Lake to Uskik Lake; 2) from the west side of Trapp Lake to the east side of Uskik Lake, continuing south out of the map-area; and 3) along the west side of the Reindeer River as far south as its junction with the Churchill River.

The metavolcanics comprise mainly fine-grained volcaniclastic rocks. Mesocratic and melanocratic hornblende granulites, hornblende gneisses and hornblende "diorites", of which there is a subordinate component, are interpreted to be metamorphic products of mafic and intermediate volcanics.

Volcaniclastics (Unit Pve)

This unit consists mostly of fine-grained rocks which have been grouped into four mappable subdivisions.

Subunit Pve1 - Most common is a dark greenish grey to light grey weathering, fine-grained, compositionally layered rock composed of various proportions of biotite, hornblende, quartz and plagioclase. Individual laminae and thin beds range from melanocratic hornblende granulites to quartz-feldspar siltites. Porphyroblasts of medium-grained hornblende and/or plagioclase are present locally. Garnet porphyroblasts are ubiquitous in the northern part of the Carruthers Lake belt. Subordinate rock types in this unit include hornblende plagioclase gneiss and homogeneous mesocratic to melanocratic hornblende granulite. This unit is admixed with gneissic equivalents and abundant quartz-feldspar pegmatites in the belt along the Reindeer River.

Subunit Pve2 - Much of the volcanic belt between Tabbernor and Uskik Lakes is a well-foliated, commonly crenulated, dark green, fine-grained amphibolite that appears homogeneous on weathered surfaces. Lakeshore exposures reveal that it has subtle compositional layering. On the west side of the Tabbernor Lake Fault there are gradational contacts between the amphibolite and intercalated members of meta-arkose (OLr).

Subunit Pve3 - This mixed subunit occurs southwest of Hebert Island, Carruthers Lake. The following rock types are included: 1) strongly foliated, buff-weathering meta- arkose that ranges from varieties containing only a few percent micaceous minerals to those with more abundant muscovite, biotite, hornblende and porphyroblasts of garnet; 2) brownish grey-weathering biotite schist, typically with porphyroblasts of garnet; 3) light grey-weathering leucocratic granodiorite to granodiorite gneiss; and 4) compositionally layered fine-grained hornblende-biotite-quartz-feldspar rock similar to subunit Pve1 but too thin to be subdivided on this scale of mapping.

Subunit Pve4 - The southern part of the Reindeer River volcaniclastic belt consists predominantly of compositionally layered quartz-feldspar siltites that host rare members of hornblende granulite and hornblende gneiss.

Subunit Pvao - Southwest of Carruthers Lake, a rare, variably deformed, polymict pebble conglomerate unit is intercalated in the volcaniclastic sequence. This unit is correlated with, and was probably once continuous with, an analogous thick conglomerate belt at Porky, Pine and Munro Lakes (Delaney, 1986).

Subunit Pve5 - Relatively pristine volcaniclastics were observed only at the west end of Uskik Lake where they comprise lapilli tuffs and layered tuffs.

Mafic and Intermediate Volcanics (Units Pvi and Pvb)

Rocks interpreted to be the metamorphosed products of mafic to intermediate volcanics are exposed in three main localities: 1) in the Trapp Lake - Tabbernor Lake area, 2) southeast of Gilson Lake, and 3) southwest of Carruthers Lake. Two main groups are distinguished:

Subunit Pbgn - The first and second localities have a "dioritic" heterogenous texture and comprise an admixture of fine-grained amphibolite, medium-

grained mesocratic to melanocratic quartz diorite, and plagioclase blastic amphibolite.

Subunits Pvip and Pvbp1 - The other main subdivisions are dark grey, fine- to medium-grained, mesocratic to melanocratic hornblende granulite-textured rocks. Millimetre- to centimetre-size blebs of plagioclase are abundant in some exposures of these subunits.

Ourom Lake Meta-arkoses (OL)

A thick sequence of meta-arkoses, siltites, metaconglomerates and gneissic equivalents of these rocks is exposed along the eastern side of the Tabbernor Lake Fault. Other, thinner sequences of this unit are intercalated in volcaniclastic rocks along the western side of the Tabbernor Lake Fault.

Meta-arkose (Unit OLr)

The sequence comprises predominantly thin- to medium-bedded, buff-weathering meta-arkose. At some localities, muscovite is the main accessory mineral, whereas elsewhere disseminated biotite generally composing less than 10 percent of the rock is common. Other parts of the unit contain varying amounts of fine- to medium-grained amphibole. Concentrations of magnetite accentuate primary structures. Trough cross-bedding is common, particularly in the western two-thirds of the main body. Other primary structures include scour surfaces and pebble lags. A horizon of slump structures several metres thick was observed at Ourom Lake; other slump structures are reported in the Manawan Lake area (Kirkland, 1976; Macdonald, 1976).

Subunit OLrp - The eastern part of the Ourom Lake Meta-arkose belt, from Ourom Lake to Tabbernor Lake, is more immature in character; several of the members in this area contain more abundant biotite and or hornblende than the rest of the belt.

Subunit OLro - A belt of metaconglomerate and metaconglomeratic beds flanks the northern end of Tabbernor Lake and is also present on some of the islands in the northern part of the lake. Pebble-size meta-arkose clasts are the most common framework constituent, although rare granitic, amphibolitic and quartz clasts are also present. Similar conglomeratic facies have been noted in the southern extension of the Ourom Lake meta-arkose in the Manawan Lake area (Kirkland, 1957, 1976).

Subunit OLgn - This unit comprises biotite-muscovite quartzofeldspathic gneiss to homogeneous medium-grained "granodiorite" which has been produced by elevated metamorphism on the northern and eastern flanks of the main belt of Ourom Lake Meta-arkose. The transition from meta-arkosic rocks to gneisses and granodiorite is gradational to locally abrupt. A horizon of faserkiesel-bearing conglomeratic meta-arkose is also found on the eastern side of the belt.

Dioritic Sills and Dykes (Unit OLbd)

Dioritic sills and dykes, which are common in the Ourom Lake Meta-arkose, decrease in number and thickness to the east away from the Tabbernor Lake Fault.

Paragneiss (N)

East of Carruthers Lake is a belt of tonalitic paragneiss and pelitic migmatite that extends south-southeast to near the mouth of the Conjuring River.

Tonalitic Gneiss (Unit N1)

Tonalitic paragneiss is leucocratic to rarely mesocratic and has a well-developed gneissosity defined by millimetre- to centimetre-thick compositional and grain-size variations. Numerous wispy-terminated leucocratic to mesocratic tonalite fragments, some of which are isoclinally folded, are present in parts of this unit.

On the northeast side of Carruthers Lake the gneiss is more heterogeneous with a variety of compositional layers, including 1) alternating mesocratic hornblende granulite and quartzofeldspathic rock, 2) leucocratic quartzofeldspathic rock, and 3) medium-grained hornblende-rich layers in a quartz-feldspar rock.

Migmatitic Schist (Unit Ngp1)

Within the core of the synform at the north end of the gneiss belt is a unit of rust-weathering migmatitic sillimanite-garnet-biotite schist. This pelitic schist hosts layers, lenses and scattered medium- to coarse-grained porphyroblasts of plagioclase. In the adjacent heterogenous gneiss are irregular areas of an interlocking mosaic of medium- to coarse-grained plagioclase.

Migmatitic Biotite Gneiss (Unit Ngp2)

Migmatitic biotite gneiss, exposed in a belt along the Reindeer River, has a homogeneous to layered pelitic paleosome of fine-grained biotite, quartz and feldspar that locally contains medium- to coarse-grained porphyroblasts of garnet and more rarely sillimanite. The leucosome comprises layers, lenses and isolated porphyroblasts of medium- to coarse-grained plagioclase. There is a gradational contact between the migmatitic biotite gneiss and compositionally layered fine-grained volcaniclastic rocks (unit Pve1) to the west.

EARLY INTRUSIVES

Granodiorite/Granodiorite Gneiss (G)

Early granodiorite, tonalite and associated quartz monzonite phases flank the northeast and southeast sides of the Eisler Lake gabbro.

Quartz Monzonite (Unit Gq3)

Quartz monzonite is a salmon red, medium-grained leucocratic rock that contains 7 to 10 percent mafic minerals of which hornblende is dominant.

Granodiorite and tonalite phases include:

Granodiorite (Unit Gd5)

On the northeast side of the Ourom Lake Meta-arkose is an extensive unit of buff-weathering, medium-grained, leucocratic granodiorite that typically contains a small amount of magnetite and is generally massive although locally foliated to gneissic. Along the western contact with the belt of Pine Lake Metavolcanics, this unit hosts numerous tabular wispy-terminated xenoliths of mesocratic to melanocratic hornblende granulite.

Leucocratic Granodiorite (Unit Gd6)

This unit, which underlies an area between Gilson Lake and Whitford Bay, comprises a medium-grained, apparently massive, buff-weathering leucocratic granodiorite.

Heterogeneous Granodiorite and Tonalite (Unit Gd7)

This is a unit of texturally heterogeneous, fine- to medium-grained leucocratic granodiorite and tonalite lying northwest of the Churchill River, near the southern boundary of the map-area.

"Fleck" Granodiorite (Unit Gd8)

This unit, which underlies some of the islands in Eisler Lake as well as an area northeast of the lake, is a "fleck" granodiorite characterized by centimetre-sized clots of fine-grained biotite, making up 3 to 7 percent of the rock, in a medium-grained framework of quartz and feldspar.

Lineated Granodiorite (Unit Gd9)

This is a medium-grained, light grey, leucocratic, strongly foliated and lineated granodiorite that includes tabular xenoliths of fine-grained siliciclastic sediments.

Some of these granodiorite and tonalite units, such as those southwest of Carruthers Lake grade through a zone of granitization, into siliciclastic metasediments.

Quartzofeldspathic Gneiss (Unit Gdgn)

Leucocratic granodiorite (unit Gd5) grades into leucocratic quartzofeldspathic gneiss at both north and south ends. This gneiss is buff to light grey weathering and strongly foliated, with foliation-parallel quartz feldspar layers and lenses. The gneiss also contains a few percent mafic minerals and abundant layers, lenses and veins of quartz feldspar pegmatite, as well as rare remnants of light grey, fine-grained granoblastic meta-arenite.

In the Manawan Lake map-area, Kirkland (1957) suggested that similar gneisses are derivatives from the Ourom Lake Meta-arkose. Later work by Macdonald (1976) also favoured this hypothesis.

Eisler Lake Intrusive (EL)

A large gabbro intrusive containing subordinate ultramafic and dioritic phases is exposed in the vicinity of Eisler Lake.

Gabbro (Unit ELbb)

Gabbro is generally massive, dark green, medium grained, mesocratic to melanocratic and composed mostly of hornblende and plagioclase. Ubiquitous disseminated pyrrhotite and rare chalcopyrite have also been observed.

Ultramafic Rock (Unit ELu)

Parts of an apparently elliptical body of massive, medium- to rarely coarse-grained ultramafic rock are exposed on the islands in and the shoreline at the north end of Eisler Lake. Petrographic studies were interpreted by Budding and Kirkland (1956) to support a pyroxenite parentage for these ultramafic rocks.

Quartz Diorite (Unit ELbd)

An irregular rim of quartz diorite and associated phases flanks the northwestern margin of the Eisler Lake Intrusive. The main rock type is a dark grey-weathering, medium-grained, massive, mesocratic quartz diorite that is gradational into gabbro. Locally, as along the western side of Eisler Lake, the quartz diorite hosts abundant fine-grained amphibolitic xenoliths and is cut by at least three different phases: coarse-grained, hornblende-rich ultramafic rock, hornblende-quartz-plagioclase pegmatite and leucocratic tonalite.

Other Basic Intrusives

Other small basic intrusives are present in the map area. The largest of these include:

Mesocratic Quartz Diorite (Unit bdl)

This unit comprises massive to foliated, medium-grained, dark greenish grey- to grey-weathering mesocratic quartz diorite on the west side of Trapp Lake.

Gabbro (Unit bbl)

An irregularly shaped body with numerous apophyses of dark green-weathering medium-grained gabbro is exposed to the west of Tabbernor Lake.

Wood Lake Batholith (WLgd)

Uskik Lake is flanked by a leucocratic granodiorite pluton. This is the northern end of the Wood Lake batholith (Kirkland, 1976), a north-south elongated body that is reported to be approximately 58 km long and 12.8 to 16 km wide.

Leucocratic Granodiorite (Unit WLgd)

On the south side of Uskik Lake, most of this pluton comprises a medium-grained, massive to rarely foliated, leucocratic granodiorite that hosts rare amphibolite xenoliths.

Mesocratic Granodiorite to Tonalite (Unit WLgdl)

Also on the south side of Uskik Lake, the margins of this pluton are well foliated, leucocratic to generally mesocratic granodiorite to tonalite with rare to abundant mafic xenoliths.

To the north of Uskik Lake, the arrangement of these units is more irregular and the juncture of the pluton with the tonalitic gneisses (unit Nl) is masked by drift.

LATE INTRUSIVES

Eyahpaise Lake Pluton (Egd)

Tonalite (Unit Egd)

The calc-alkaline Eyahpaise Lake Pluton bounds the western side of the map-area. Generally this is a homogeneous, medium-grained, massive tonalite containing 3 to 5 percent mafic minerals, of which medium- to coarse-grained hornblende is most abundant. Around Stephens Lake, however, the tonalite contains between 7 and 15 percent mafic minerals. The pluton has yielded a U-Pb date of 1859±5 Ma (Lewry et al., in press).

Quartz Diorite (Unit Egdl)

As noted by Budding and Kirkland (1956), there is a distinct marginal phase along much of the eastern part of the Eyahpaise Lake Pluton. This bounding phase is mineralogically and texturally variable. To the east of Eisler Lake, the marginal phase is a leucocratic to mesocratic quartz diorite with abundant xenoliths of amphibolite near its eastern contact. In contrast, at the southern end of Munro Lake, there appears to be greater mineralogical variability and subunit Egdl does not appear to be as laterally continuous (Lewry, 1977; Delaney, 1986). The eastern margin also lacks a major shear zone like the Laonil Lake Shear Zone along the northern margin.

Granodiorite (Unit SLgd)

A granodiorite plug, 1.5 km in diameter with a dioritic margin, intrudes the Eyahpaise Lake Pluton northeast of Stephens Lake. The core of this intrusive is a massive, medium-grained leucocratic granodiorite with 7 to 12 percent mafic minerals that are mostly biotite. Unit SLgd has yielded a U-Pb date, on separated zircons, of 1836±7 Ma (Lewry et al., in press).

Diorite (Unit SLbd)

The granodiorite core is mantled by and intrudes a medium-grained mesocratic diorite that contains lenses of ultramafic rock.

Pegmatite (Unit Peg)

Pegmatite of several types is common in many places. The commonest variety is massive buff to pink weathering and composed of quartz, feldspar and biotite.

STRUCTURAL GEOLOGY

Folding Events

A preliminary analysis of small- and large-scale structures indicates that at least three folding episodes affected the area.

F_1 folds comprise a series of large-scale north-northwest- to north-trending, assymetrical to isoclinal antiforms and synforms, some of which were described previously by Budding and Kirkland (1956). S_1, a prominent bedding-parallel foliation and gneissosity, is well developed throughout much of the area. A strong mineral lineation (L_1) developed near the closure of some of the

structures, parallels the axial trend. These folds are complex in character, exhibiting great variability in style along their axial trace.

F_2 folds are defined by a strong crenulation cleavage (S_2) that is most commonly developed in the hinges of small-scale assymetrical folds. These structures are most abundant in an area that flanks the Tabbernor Lake Fault. Although most commonly northeast trending, orientations are somewhat variable and more than one deformation event may be present.

Evidence of a third folding event was only observed east of the Tabbernor Lake Fault near Ourom Lake where an east-southeast-trending cleavage (S_3) cuts both the bedding parallel S_1 foliation and the S_2 crenulation cleavage.

Lewry (1977) observed that minor structures in the northeastern part of the adjacent Glennie Lake map-area are coaxial with the Carruthers Lake Antiform. Lewry (op. cit.) further noted that the north-northeast-trending minor structures deform an earlier foliation. By extrapolation, these relationships are interpreted to indicate that, although only three deformational episodes were documented in the study area, it was probably also subjected to an earlier unrecognized episode.

Tabbernor Lake Fault

The Tabbernor Lake Fault in the area is marked by a distinct linear topographic depression that hosts streams and narrow long lakes. Outcrop exposures of the fault trace are scarce. Adjacent to the fault trace, on Tabbernor Lake, there are narrow zones of tectonic breccia or mylonite in the Ourom Lake meta-arkoses.

In general the Tabbernor Lake Fault is flanked by a distinct alteration halo which is most pronounced in the laminated amphibolites of subunit Pve2 between Tabbernor and Uskik Lakes. The halo here is of irregular thickness, locally up to several hundred metres wide, and has been subjected to a variety of alteration processes including epidotization, hematization and chloritization. In contrast, alteration phases in meta-arkose flanking the Tabbernor Fault are generally confined to a narrow zone along the fault, and these include epidote coatings on fracture surfaces and hematitic staining.

The Tabbernor Lake Fault has been recognized as a fundamental crustal structure characterized by an abrupt metamorphic gradient and well-defined parallel fold belt (Budding and Kirkland, 1956; Kirkland, 1957, 1976; Macdonald, 1976; Sibbald, 1978; Lewry, 1981a). In the study area, this fault marks the western margin of an extensional basin that hosts a sequence of fluvial and shallow water siliciclastics, the Ourom Lake Meta-arkoses. Abundant but narrow dykes and sills of diorite that intrude the Ourom Lake Meta-arkoses were probably emplaced during or shortly after deposition of the meta-arkoses. These intrusives may be evidence that a deep-rooted fault or fault system was the locus of this extensional basin. To the west, facies of the Ourom Lake Meta-arkoses grade into fine-grained volcaniclastic strata of the Pine Lake Metavolcanics. To the east, the Ourom Lake Meta-arkoses grade into more argillaceous basinal facies.

ECONOMIC GEOLOGY

Several copper showings are known in the area. Because some of these are known to host elevated concentrations of gold and silver, many are being re-evaluated. The following section, based primarily on assessment file data supplemented by observations of the author, presents a brief review of exploration activity and style of mineralization at the significant showings.

Carruthers Lake Area

Car 1

This showing is located on the north shore of the peninsula at the east end of the narrows near the middle of Carruthers Lake (No. 1 on Fig. 1; UTM co-ordinates 599600mE, 6173100mN). J. Studer staked this prospect in 1965 and dug six pits (Assessment File 63M11-0007, Saskatchewan Energy and Mines, Regina). In 1968, Great Plains Development optioned this ground and included it in a detailed geological and geophysical investigation of the Carruthers Lake area. They reported that grab samples collected by J. Studer contained up to 2 percent Cu, 20.5 g/t (0.6 oz./ton) Au and 24.0 g/t (0.7 oz./ton) Ag (Assessment File 63M11-0016). Examination of this showing revealed that it is hosted in a thin-bedded, strongly-foliated sequence of dark green-, grey- or light grey-weathering, fine-grained, biotite hornblende metavolcaniclastic and metasedimentary rocks. Over an interval of approximately 5 m, there are five rusty-weathering calc-silicate beds that contain visible disseminated pyrrhotite. These beds range in thickness up to 0.5 m and can be traced for at least 30 m along strike to the north. This showing appears to be a syngenetic stratiform-hosted occurrence.

Earna

This showing (No. 2 on Fig. 1; UTM co-ordinates 599550mE, 6171400mN) is located approximately 1.6 km south of the Car 1. The first reported work in this area was by Hudson Bay Mining and Smelting Co. Ltd., who in 1957 completed a geophysical survey as well as eight trenches over the showing. In 1968, Great Plains Oil and Gas Ltd. staked a large claim block (CBS 1401 and 1406) that included the Earna showing. Investigations included trenching, detailed mapping, geophysical surveys

and diamond-drilling. This prospect is reported to be hosted in a dextral fault zone cutting a sequence of cordierite-garnet-actinolite-biotite gneiss and garnet-biotite gneiss. Within the fault zone, chalcopyrite is present in narrow veins as well as in stringers, blebs and disseminations over widths of from 0.3 to 1.2 m. A 1100 m long gossan delineates the mineralized zone. Five drillholes at three locations which tested the showing returned up to 0.29 percent Cu, 3.5 g/t (0.1 oz./ton) Ag and concentrations of less than 0.4 g/t (0.01 oz./ton) Au (Assessment File 63M11-0016).

Eisler Lake Area

DD

This property is currently held by Calpine Resources under option from Claude Resources. The showing is hosted in the west-trending curvilinear shear zone marked by the valley at the northwest corner of Eisler Lake (No. 3 on Fig. 1; UTM co-ordinates 599300mE, 6164450mN). The mineralized shear, which cuts metagabbro, is reported to have been traced over a strike length of 700 m (Northern Miner, 1986a). Fifty-two chip samples from five trenches included 14 samples with gold values in excess of 100 ppb and six samples with 1.1 to 7.9 g/t (0.032 to 0.23 oz./ton) Au (Northern Miner 1986b, 1986c). Early in 1987, Calpine completed five drillholes (686 m) on the showing (Northern Miner, 1987). Only preliminary assay results have been announced for this work. These included elevated gold values in holes 1 (370 ppb over 1.2 m) and 2 (140 ppb over 5.5 m).

FM

This showing (No.4 on Fig.1; UTM co-ordinates 602600mE, 6161950mN) is marked by a small trench at the end of a 1.2 km long trail to the southeast from the east arm of Eisler Lake. In 1954, three drillholes, each about 30 m long tested the showing and it was also trenched (Budding and Kirkland, 1956). In the fall of 1955, H. Freeman staked the FM group of nine claims. Beck (1959, p.70) reported that "disseminated pyrite and chalcopyrite occur in quartz-carbonate veinlets in a five-foot wide zone of sheared and silicified hornblende gneiss. Very thin seams of sulphides also occur along some of the shear planes". Brief logs for the holes (Assessment File 63M11-0001) revealed that they cut a texturally variable body of gabbro that includes what were logged as diorite and amphibolite. Some mottled alteration phases were also noted. Only trace amounts of chalcopyrite were observed and no assay values were reported.

Small Lake Showing

(No. 5 on Fig. 1; UTM co-ordinates 603380mE, 6161880mN). Disseminated pyrite and chalcopyrite occur in quartz-carbonate veinlets in a sheared and fractured metagabbro zone 1 by 4.5 m in size (Budding and Kirkland, 1956; Assessment File 63M11-0022).

Tabbernor Lake Area

Small Lake North of Tabbernor Lake

This prospect, located on the south shore of the small lake north of Tabbernor Lake (No. 6 on Fig. 1; UTM co-ordinates 606500mE, 6172800mN), is between two major splays of the Tabbernor Lake Fault. The main showing is reported to be a 9 m wide gossan developed over pyrite bands that preferentially replace biotite-rich layers in gneisses. Inspection this past summer revealed that the host sequence is a biotite hornblende quartzofeldspathic gneiss (7 to 10 percent total mafics) that at the showing is sheared and silicified. A trench along the lake shore is reported to expose chalcopyrite and sphalerite stringers across 3.5 m. Analyses of a 15 cm grab sample returned the following results: trace Au, 18.5 g/t (0.5402 oz./ton) Ag, 2.44 percent Zn and 0.54 percent Cu (Assessment File 63M11-0023).

Small Lake South of Tabbernor Lake

This showing (No. 7 on Fig. 1; UTM co-ordinates 608550mE, 6172800mN) is located approximately 1.6 km south-southeast of Tabbernor Lake on the west side of the small linear lake. The mineralized zone, trenched in 1973 and 1974, is reported to be a 30 to 45 cm wide chalcopyrite vein with some pyrite and sphalerite in a sheared and folded hornblende gneiss. Grab samples of the vein are reported to have yielded high values of Cu, Au and Ag, but no actual assay results are presented with the Assessment Report (Assessment File 63M11-0033). Core Energy Corp optioned the property that hosts this showing from Claude Resources and completed three holes totaling 270 m in 1987 (Canadian Mines Handbook, 1987). The results of this drilling are not known.

Uskik Lake Area

Wek

The main showing is on the west shore of the Churchill River approximately 1 km south of where the river widens into Uskik Lake (No. 8 on Fig. 1; UTM co-ordinates 604500mE, 6153750mN). Mineralization is hosted in a texturally irregular sequence of dioritic hornblenditic rocks that are partially granitized. In 1955, K. Wierzycki staked three groups of claims that included this showing (Beck, 1959). In 1956, Wierzycki completed trenching and four diamond-drill holes (368 m) to test the prospect. Interesting intersections include 0.8 m in hole 2 that returned 0.24 percent Cu and

1 g/t (0.03 oz./ton) Au, and 0.5 m in hole 3 that contained 0.08 percent Cu and 11.6 g/t (0.34 oz./ton) Au (Assessment Files 63M11-0002 and 63M11-0003). Hudson Bay Mining and Smelting Co. Ltd. optioned the claims and completed an electromagnetic survey over the area of the showing in 1958. No conductors were located and no further work carried out. In 1969, Oro Mines, who had optioned the showing from K. Studer, undertook a new electromagnetic and magnetic study on the property, as well as drilling 91 m in four additional diamond-drill holes. Several intervals in these holes contained anomalous concentrations of gold, silver and copper. The best intersection was in hole 2 where a 0.9 m interval assayed 42.5 g/t (1.26 oz./ton) Au, 59 g/t (1.70 oz./ton) Ag and 2.44 percent Cu. This mineralization is hosted in what was logged as a diorite-textured quartz-hornblende-biotite schist with both disseminations and blebs of chalcopyrite (Assessment File 63M11-0020). Glitter Gold Mines Ltd. completed an additional drilling program on this property in 1986. The results of this work are not known.

Kaz

This prospect (No. 9 on Fig. 1; UTM co-ordinates 602450mE, 6156200mN) is on the northwest side of the small amoeboid-shaped lake approximately 3 km northwest of the Uskik showing. The property was staked by K. Parada in 1967 and later optioned to Cominco who evaluated it with a program that included geological mapping, soil sampling, geophysics and diamond-drilling. The mineralized area is reported to consist of lenses of chalcopyrite, magnetite and minor disseminated bornite in a series of narrow en-echelon shears in a 20 to 30 m wide, highly foliated zone in amphibolite gneiss. Grab samples from the trenches yielded up to 0.80 percent Cu, 6.9 g/t (0.2 oz./ton) Ag and 0.4 g/t (0.01 oz./ton) Au. Cominco completed two diamond-drill holes totalling 297 m. Drillhole no. 1 is reported to have intersected two mineralized zones; one of these assayed 0.568 percent Cu across 10.5 m and the other assayed 0.56 percent Cu across 9.5 m. Some narrower 1.5 m segments within this later interval assayed up to 20.5 g/t (0.60 oz./ton) Ag and 1.0 g/t (0.03 oz./ton) Au. Drillhole no. 2 had a 0.5 m thick interval that contained 1.89 percent Cu (Ag and Au were not analyzed for) and another 1.5 m thick interval that assayed 0.07 percent Cu, 30 g/t (0.88 oz./ton) Ag and 0.7 g/t (0.02 oz./ton) Au (Assessment Files 63M11-0014 and 63M11-0021).

SYNTHESIS AND RECOMMENDATIONS FOR FUTURE PROSPECTING

The most attractive exploration target in the map-area is stratiform, syngenetic gold mineralization like that discovered at the Car 1 showing. This showing is hosted in volcaniclastic subunit Pve3, a heterogeneous assemblage of meta-arkose, biotite schist, granodiorite gneiss and compositionally layered fine-grained hornblende-biotite-quartz-feldspar rock. Mineralized beds display a distinctive rusty weathering. Several favourable horizons were noted in exposures of this unit flanking the narrows in the middle of Carruthers Lake.

Anomalous concentrations of gold are associated with copper showings in fault and fracture zones. These mineralized zones have been discovered at several locations in a variety of rock types. Although no significant mineralized zones have been discovered yet, this type of deposit is an attractive target particularly in larger scale fault zones. In addition to the obvious target of the Tabbernor Lake Fault, which hosts several copper showings (i.e., Budding and Kirkland, 1956), another area that warrants detailed investigation is the southwest-trending curvilinear fault that cuts the small lake east of Gilson Lake. A favourable indicator along this lake is a quartz-tourmaline vein that superficially at least looks similar to those found at the Seabee deposit. Perhaps a more mineralized variety lies elsewhere along the trace of the fault zone.

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Project 8712

Bedrock Geological Mapping, Bing Lake Area (Part of NTS 73P-7 and -10)

by D.J. Thomas

Thomas, D.J. (1987): Bedrock geological mapping, Bing Lake area (part of NTS 73P-7 and -10); in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

This report describes the author's fourth and final year of revisional bedrock mapping at 1:20,000 scale of the southern portion of the Central Metavolcanic Belt (Thomas, 1984, 1985a, 1985b and 1986). The main aim of this project has been to provide more detailed geological information in an area of high gold exploration potential. This summer, mapping was completed in the most southerly part of the belt.

The Bing Lake area covers 200 km^2, with the centre of the area lying about 56 km northeast of La Ronge, to which it is connected by Highway 102. The area has been previously geologically mapped, either entirely or in part, by McLarty (1935), Padgham (1960, 1963), Lewry et al. (1980) and Abraham (1985), and is included in the 1:250,000 scale regional geological compilation of the Lac La Ronge area by Lewry and Slimmon (1985).

The Bing Lake area is underlain, from west to east, by north-trending rocks of the Central Metavolcanic Belt, McLennan Group and MacLean Lake Belt, all of which belong to the La Ronge Domain (Fig. 1). Interpretation of regional geological, geochemical and geochronological data from the Central Metavolcanic Belt supports a Middle Proterozoic (ca. 1875-1870 Ma) island arc setting (Bickford and Van Schmus, 1985; Van Schmus et al., 1985; Watters and Armstrong, 1985; Harper et al., 1986; Coombe et al., 1986; Thomas and Watters, 1987; Watters et al., 1987; Lewry et al., 1987). The MacLean Lake Belt to the east is interpreted as a stratigraphically equivalent 'greywacke' basin to the Central Metavolcanic Belt, whereas the McLennan Group represents a younger molasse-like fluvial succession. Major plutonism in the Central Metavolcanic Belt appears to have spanned the period between 1870 and 1830 Ma ago, with peak regional metamorphism affecting rocks prior to 1850 Ma ago.

Supracrustal Rocks of the Central Metavolcanic Belt

Supracrustal rocks of the Central Metavolcanic Belt underlie about 40 percent of the western half of the map area and occupy two belts which are separated by a series of large intrusions. Metavolcanic lithologies constitute more than 80 percent of this supracrustal succession, while metasediments are most prevalent in the eastern belt. Intermediate gneisses and schists (15 to 35 percent mafics) represent 90 percent of the metavolcanic assemblages. Subordinate mafic (greater than 35 percent mafics) and only minor felsic metavolcanic rocks are present. Although not generally preserved, primary textures and depositional structures are somewhat more prevalent in the eastern belt and only locally observed in the western belt.

Eastern Belt

The Eastern Belt forms the southerly extension of a sequence of mixed metavolcanic and volcanogenic metasediments previously described between Wapiyao and Milner Lakes (Thomas, 1986). This mixed assemblage extends south of Milner Lake to Welk Lake and corresponds well with a prominent regional linear aeromagnetic 'high'. The rocks comprise a homoclinal sequence between 1000 and 2000 m thick overturned to the east, with the lower part of the sequence cut off by intrusive rocks to the west. Mafic metavolcanic flows northwest of Welk Lake are postulated to form the lowest stratigraphic portion of this belt. These flows are overlain by a sequence of largely undivided intermediate metavolcanics ranging from 100 to 1000 m in thickness. The absence of fragmental textures and the presence of occasional quartz-feldspar amygdules in these intermediate metavolcanics suggest they are predominantly lava flows.

A particularly striking member of this intermediate metavolcanic unit is a coarse feldspar-porphyritic 'trachytic' metaflow that contains from 10 to 40 percent plagioclase laths, locally exceeding 5 cm in length. This member occurs in a composite package of flows which are interbedded with narrow horizons of interflow metasediments. Between Milner and Cathro Lakes, this package contains two major 'trachytic' horizons, 100 to 200 m wide, which are separated by about 200 to 400 m of nontrachytic flows and metasediments.

Overlying and interbedded in part with the intermediate metavolcanic rocks are discontinuous lenses of psammopelitic to pelitic schists. Along

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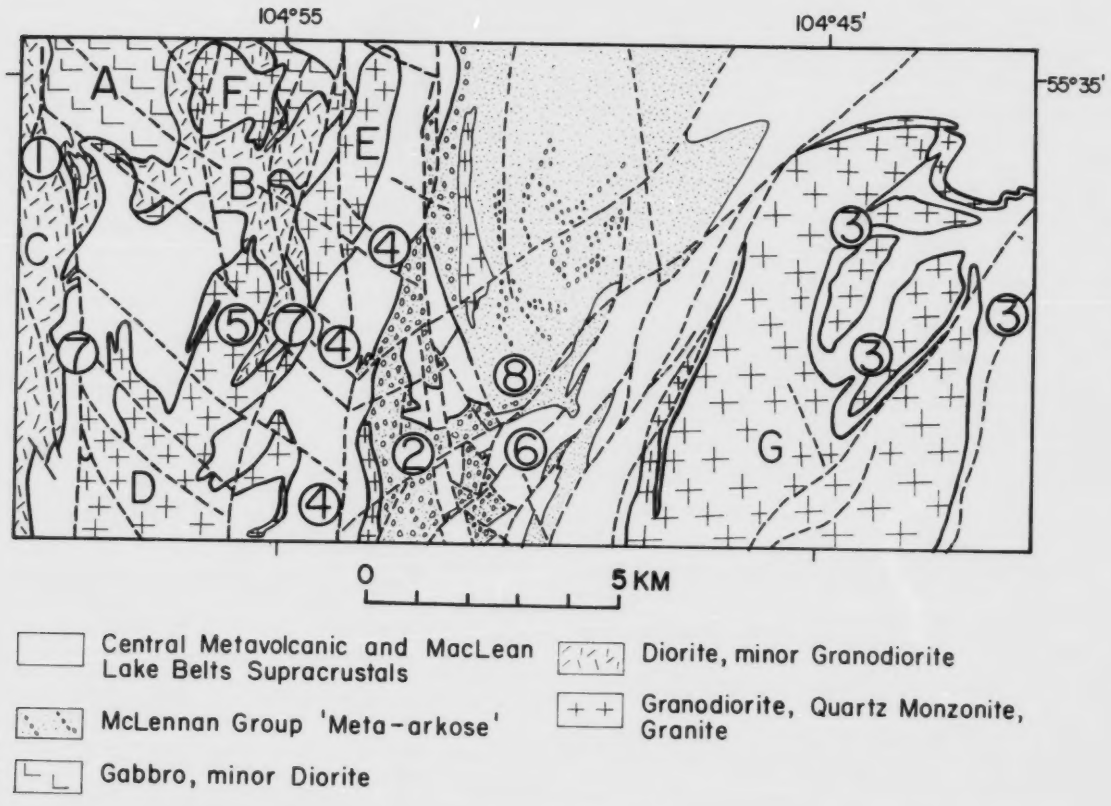

Figure 1 - General geology of the Bing Lake area. Bassett Lake Intrusion (A), Beranek Lake Intrusion (B), Bartlett Lake Intrusion (C), Welk Lake Intrusion (D), Bing Lake Intrusion (E), Hood Creek Intrusion (F), Bridgeman Lake Pluton (G). Numbers refer to locations cited in "Suggestions to Explorationists" section in text.

the eastern part of the belt these metasediments grade into polymictic psammopelitic metaconglomerates which form narrow discontinuous lenses generally less than 5 m thick, and also larger wedge-like units up to several tens of metres thick. The metaconglomerates are generally clast supported but locally possess a matrix-supported framework composed of biotite, chlorite, amphibole and lesser amounts of quartz and feldspar. Clasts range from pebble size (4 to 64 mm) through to cobble size (64 to 256 mm), and consist of various plutonic and metavolcanic rocks similar to those in the volcanic-plutonic succession in the area.

Western Belt

The Western Belt of supracrustal rocks forms an elongated heart-shaped outcrop extending from Thornton Lake to Bartlett Lake. In contrast to the high aeromagnetic signature of the eastern belt, these supracrustals are distinguished by relatively lower aeromagnetic values. The distribution of a distinctive felsic metavolcanic marker horizon in the main part of the belt suggests the sequence may form a large 'closed' fold interference structure.

The percentage of various rock types present and their stratigraphic relationships are difficult to determine due to extensive glacial drift cover; however, intermediate metavolcanic lithologies appear to be more prevalent than mafic varieties and felsic metavolcanic rocks are very minor. The north end of Bartlett Lake has a high proportion of intermediate heterolithic metatuff-breccias and lapilli metatuffs which grade southward into finer grained, intermediate to locally mafic metatuff, meta-argillite and psammitic members. A problematic rock type, previously described in the Onipoowuk Lake area (Thomas, 1986), is present in the western supracrustal belt. It is typically a fine-grained, mesocratic, locally feldspar-porphyritic rock of intermediate or dioritic composition. Generally structureless, except for a weakly-developed penetrative foliation, it locally

contains minor bands of recognizable metavolcanic material. This particular rock may represent a series of composite 'andesitic' flows and/or in part feldspar crystal tuffs. Alternatively it may represent dioritic sills.

A narrow discontinuous zone of intermediate and mafic lapilli metatuff, garnetiferous pelitic schist and minor mafic metaflows is preserved between intrusive rocks around Bing Lake. This zone may represent a remnant of the stratigraphic sequence linking the two main supracrustal belts.

MacLean Lake Belt

The MacLean Lake Belt comprises a predominantly northeast-trending metasedimentary assemblage in the eastern part of the map area that structurally underlies the McLennan Group occurring to the west. Interpretation of the stratigraphy of this belt is speculative; nevertheless, a few generalizations can be made:

1) The lowest structural unit comprises amphibolitic gneiss and calc-silicate gneiss with minor biotite schist, and varies in thickness from 400 m in the west to 800 m in the east. The amphibolites are typically medium to coarse grained and dark greenish-black to dark greenish-grey with a moderate- to well-developed schistosity. Delicate millimetre-scale gneissic layering is commonly developed. Calc-silicate beds, from 1 to 50 cm thick and consisting of variable amounts of diopside, actinolite, plagioclase and quartz, are prevalent in the Dyer Lake area. Small gossan zones containing pyrite, pyrrhotite and arsenopyrite are locally developed in the calc-silicate member.

2) Overlying the amphibolite unit in the Hine - Bielby Lakes area is approximately 200 to 400 m of fine- to medium-grained, greyish yellow-green to pale greyish-green calcareous psammitic gneiss. The calcareous psammites give way to noncalcareous psammitic and psammopelitic rocks in the eastern part of the area, while minor polymictic psammitic metaconglomerate lenses are developed locally throughout this stratigraphic unit.

3) A discontinuous calc-silicate assemblage, averaging less than 50 m thick, is developed at the top of the psammitic-psammopelitic unit in the eastern part of the area. The calc-silicate rocks, composed of variable amounts of diopside, actinolite, tremolite, muscovite, biotite, epidote, calcite, plagioclase and quartz, are interbedded with lesser amounts of amphibolitic pelites and calcareous psammites.

4) The highest structural unit in the succession comprises 200 to 400 m of interlayered pelitic and psammopelitic schists. A distinctive member of this unit is a 10 to 50 m wide layer of medium- to coarse-grained, light grey to light brownish-grey pelitic gneiss containing 10 to 30 percent garnet. Garnets (2 to 10 mm diameter) are concentrated in 5 to 20 cm wide layers which give the rock a strongly banded appearance. Polymictic psammitic metaconglomerates found along Otter Lake in the northeastern part of the area, which occur towards the top of this pelitic-psammopelitic unit, generally form lensoid beds which grade laterally and vertically into greyish psammites. The metaconglomerates typically possess a clast-supported framework of psammitic to psammopelitic cobbles with lesser plutonic and rare mafic clasts. The matrix consists of a pelitic assemblage of biotite, hornblende, actinolite, epidote and occasionally calcite.

Central Metavolcanic Belt-MacLean Lake Belt Transition

The southern part of the Bing Lake area provides one of the few exposed sections of the junction between the Central Metavolcanic and MacLean Lake Belts. The section, which extends from Berg Lake to Althouse Lake, is composed of complexly interlayered rocks typical of each belt. The transition is marked by an overall eastward decrease in hornblende-plagioclase gneiss, intermediate to mafic metavolcanics and polymictic psammopelitic metaconglomerates, with a corresponding increase in psammopelitic, pelitic and calcareous psammitic rocks. Recognition of a lateral gradation between the two belts suggests at least partial stratigraphic equivalence; therefore, the relationship between the two belts is tentatively interpreted as a diachronous transition.

McLennan Group

The McLennan Group comprises up to 1500 m of potassium feldspar-rich meta-arenites and metaconglomerates which occupy the core of a major north-northeast-trending synform in the central part of the area. Field evidence indicates the McLennan Group disconformably overlies the Central Metavolcanic Belt and probably the MacLean Lake Belt as well.

The basal portion of the McLennan Group consists of discontinuous lenses of polymictic arkosic metaconglomerate which grade laterally into 'granitic' meta-arkose and quartz-eye meta-arkosic grits. The metaconglomerates contain an assortment of clasts, including mafic and intermediate metavolcanics, metasedimentary rocks and granitic and dioritic intrusives, which occur in a matrix-supported 'arkosic' framework. Clasts range from pebble size (4 to 64 mm) to locally cobble size (64 to 256 mm), while granule-size quartz grains commonly give the rocks a 'quartz-eye' gritty appearance. At Cathro Lake

and north of Berg Lake, this basal assemblage lies disconformably on polymictic psammopelitic metaconglomerates of the Central Metavolcanic Belt.

The basal assemblage grades vertically into a lithology containing increasing amounts of oligomictic metaconglomerate, which consists of a clast-supported framework of 'granitic' clasts ranging from pebbles (4 to 64 mm) through cobbles (64 to 256 mm) and locally to boulders (greater than 256 mm). Individual conglomerate beds vary in thickness from a metre to several tens of metres, and are interbedded with and grade laterally into quartz-eye meta-arkosic grits and massive 'granitic' meta-arkose. Conglomerate lenses appear to decrease in thickness from southeast to northwest and decrease volumetrically upwards through the succession.

The oligomictic 'granitic' metaconglomerates are overlain by an assemblage of 'granitic' meta-arkose, quartzitic meta-arkose, arkosic muscovite schist and minor quartz pebble arkosic metaconglomerate. Vague compositional and grain-size variations in this upper assemblage define bedding sets from less than one metre to several metres thick. Scour channels, cross-laminated trough sets and planar cross-laminated bedding are locally preserved. Sillimanite-quartz aggregates (faserkiesel), which are prevalent in areas to the north (Thomas, 1985, 1986), are rare in the Bing Lake section of the McLennan Group, and are largely replaced by coarse muscovite sheaves. Magnetite- and ilmenite-bearing layers were noticably more prevalent in the Bing Lake section than elsewhere in the McLennan Group. An interesting ilmenite-bearing fuchsite-quartz schist occurs in a pegmatitic metaconglomerate horizon in the northern part of the area.

Intrusive Rocks in the Area[1]

Intrusive rocks in the Bing Lake area are divided into three main groups: 1) early intrusions that are postulated to predate the McLennan Group, 2) late intrusions which intrude the McLennan Group and 3) minor dykes and sills. The early intrusions were initially gabbroic to dioritic (e.g., Bassett Lake, Beranek Lake and Bartlett Lake Intrusions) and were followed by granodioritic, quartz monzonitic and granitic bodies (e.g., Bartlett Lake, Welk Lake, Bing Lake and Hood Creek Intrusions, and the Bridgeman Lake Pluton). The late intrusions include leucogranite to aplogranite stocks which are predominantly confined to the McLennan Group.

[1] All major intrusions in the area have been affected by late regional metamorphism; however, the prefix meta- has been omitted from the lithologic names.

Bassett Lake Intrusion

The Bassett Lake Intrusion is a hook-shaped basic body producing a pronounced regional magnetic high (Federal-Provincial aeromagnetic map 4800G, Otter Lake). The northern part of the intrusion has been described by Harper (1983), Thomas (1986) and Graham et al. (1986). The intrusion consists of mesocratic to melanocratic gabbro and norite, subordinate leucogabbro, anorthositic gabbro and dioritic gabbro.

Orthopyroxene, clinopyroxene and olivine are locally preserved in the west and most of the rocks display varying degrees of uralitization and sausseritization. Rhythmic layering and cumulate textures are locally preserved throughout the body. The intrusion of granodiorite sheets along the southwest and east flanks of the intrusion has resulted in a hybrid dioritic gabbro member. The southern portion of the Bassett Lake Intrusion is cut by the dioritic Beranek Lake and granodioritic Hood Creek Intrusions.

Beranek Lake Intrusion

The Beranek Lake Intrusion is an irregularly shaped dioritic body extending through the Beranek Lake and Bing Lake area. Coarse- to medium-grained, greenish-black mesocratic diorite and dioritic gabbro occur in the north and fine-grained greyish-green microdiorite and quartz diorite occur in the south. The coarse diorites in the northern part appear to merge diffusely with gabbroic members of the Bassett Lake Intrusion. The temporal relationship between the Beranek Lake Intrusion and Bassett Lake Intrusion was not unequivocally established during this study, although Graham et al. (1986) suggest the Beranek Lake Intrusion is younger.

The transition between the coarse diorites in the north and microdiorites in the south is more abrupt near the north end of Beranek Lake. Fine-grained diorites and microdiorites, present locally in the north, appear to be the youngest rocks of the intrusion. Intrusion breccias and agmatitic migmatites (dioritic neosome with metavolcanic paleosome) occur along the southwestern margin in contact with intermediate to mafic metavolcanic rocks. Discrimination between fine-grained feldspar phyric mafic metavolcanic rocks and feldspar-porphyritic microdiorites along the southwest sides of Beranek and Bing Lakes is locally unresolved and awaits further petrographic work.

The main mafic mineral is hornblende (20 to 35 percent), although actinolite (5 to 10 percent) and subordinate biotite (less than 8 percent) are locally important. Microdiorite varieties commonly host small blocky plagioclase crystals ranging from 2 to 4 mm diameter.

Bartlett Lake Intrusion

The Bartlett Lake Intrusion, in the western part of the area is a composite body comprising interlayered sheets of nearly massive to well foliated diorite, quartz diorite and granodiorite. A complex series of north-trending sheets of granodiorite, ranging from 1 to 300 m wide, cut hornblende diorite, quartz diorite and minor dioritic gabbro. Intrusion breccia margins exist in some larger granodiorite sheets. Injection migmatites are locally developed in supracrustal rocks along the eastern side of the intrusion. Diorite and quartz diorite are typically fine- to medium-grained, medium grey to greenish-grey equigranular rocks.

Hornblende (15 to 35 percent) is generally partially altered to chlorite, and biotite rarely exceeds 5 percent. In contrast, the granodiorites are generally coarser grained and paler in colour, greyish pink to yellowish grey and more inequigranular. The main mafic minerals are coarse biotite flakes (5 to 10 percent) and hornblende (nil to 2 percent).

Welk Lake Intrusion

The Welk Lake Intrusion is an irregularly shaped body underlying about 11 km^2 in the southwest which comprises relatively homogeneous biotite trondjemitic granodiorite to granodiorite with minor quartz monzonite and granite. There is a diffuse transition between the granodiorites and quartz monzonitic to granitic phases marked by a gradual increase of K-feldspar over several metres to tens of metres. About 15 percent of the intrusion is massive, while the remainder possesses a moderate to well-developed foliation. The rocks are uniformly coarse grained. The trondjemitic granodiorite varieties are very light grey to pinkish grey and the quartz monzonitic varieties are greyish orange. Biotite is ubiquitous (3 to 12 percent), while subordinate muscovite (1 to 5 percent) occurs as both fine and coarse ragged flakes. Coarse cubes of magnetite and pyrite locally form up to 1 percent of the rock.

Bing Lake Intrusion

The Bing Lake Intrusion, north of Bing Lake, comprises mainly biotite granite but grades southwards into granodioritic to quartz monzonitic rocks petrographically similar to those in the Welk Lake Intrusion. The intrusion has a discrete contact in the east with metavolcanic and metasedimentary rocks, but the western contact is considerably more irregular and includes injection migmatites incorporating diorites of the Beranek Lake Intrusion and metavolcanic rocks. The main component of the intrusion is a coarse- to medium-grained inequigranular pink to greyish orange-pink biotite granite. Granodiorite and quartz monzonite which also occur are typically yellowish grey to pinkish grey and possess a more equigranular medium-grained texture. Although all varieties appear in the field to be essentially massive to only faintly foliated, microscopic examination reveals a pervasive cataclastic texture throughout much of the intrusion.

In thin section, the rocks display a fine-grained granulated groundmass mosaic incorporating larger granoblastic quartz and feldspar aggregates. Distinctive dark green to yellow-green pleochroic biotite is a minor component (2 to 3 percent) of the granite but a major constituent (5 to 10 percent) in the granodiorite and quartz monzonite. Late, coarse muscovite flakes are present in the more quartz-rich granite varieties.

Bridgeman Lake Pluton

The Bridgeman Lake Pluton is a crescent-shaped intrusion underlying about 25 km^2 in the east. Two smaller elliptical intrusions situated in the embayment of the 'crescent' are considered to be cupolas of the main pluton. The main body comprises 1) an 'early' gneissic granodiorite along the western northern margins of the intrusion and 2) a 'younger' albite granite to quartz monzonite which forms the main intrusion as well as the two smaller cupolas. The contact between the two components is discrete, although narrow sheets of albite granite intrude gneissic granodiorite up to several tens of metres from the contact. The contact of the pluton with the country rocks is also discrete, with very few peripheral dykes and sills. Quartzofeldspathic segregations, feldspathization and epidotization of the immediate country rocks occur only on a minor scale.

The gneissic granodiorite is relatively homogeneous in the south but progressively more migmatitic to the north. North of Bousfield Lake, these migmatitic granodioritic gneisses include agmatitic, veined, schlieric and nebulitic textural varieties. Several mappable 'keels' of supracrustal rocks are preserved in this part of the pluton. The gneissic granodiorite is typically inequigranular, medium to coarse, pale orange to pinkish grey and possesses a marked 'swirly' gneissic banding 1 to 3 cm wide. The principal mafic mineral is biotite (5 percent), although hornblende (1 to 8 percent) is locally dominant. In thin section, the granodiorites commonly display a cataclastic fabric defined by a reticulate network of finely crushed and granulated material.

The albite granite/quartz monzonite varies laterally between coarse porphyritic (microcline) granite, nonporphyritic medium- to coarse-grained albite granite/quartz monzonite, fine-grained aplogranite and gneissic quartz monzonite. The transition between the varieties is gradual over distances of several tens of metres, and cross-cutting relations were not observed. The albite granite/quartz

monzonite is typically orange pink to light red, inequigranular to locally porphyritic and medium to coarse grained, although fine-grained varieties are locally present (e.g., aplogranite). Mafic minerals comprise biotite (2 to 5 percent), minor hornblende (1 to 2 percent) and muscovite (0 to 2 percent). Porphyritic varieties contain blocky microcline phenocrysts 1 to 8 cm in length.

Hood Creek Intrusion

The Hood Creek Intrusion is a small granodioritic body intruded into the Beranek Lake and Bassett Lake Intrusions. The western part is poorly exposed, although granodiorite dykes up to several metres wide are prevalent in the surrounding country rocks and are probably related to this body. The granodiorite varies from pinkish grey to yellowish grey and is medium to coarse grained, although fine-grained variants are also present. The intrusion ranges from massive to strongly lineated biotite aggregates in the north, to well foliated in the south. Biotite (10 to 15 percent) forms coarse lenticular aggregates. Hornblende (0 to 3 percent) is present as isolated xenoblastic grains or as small subidioblastic crystals within the biotite aggregates. Quartz (20 to 25 percent) occurs in elliptical aggregates up to 2 mm in diameter. Subordinate xenoblastic microcline (3 to 4 percent) occurs in an interstitial groundmass between variably saussuritized plagioclase laths (50 to 65 percent). Coarse pyrite cubes are common.

Late Intrusions

'Late' intrusions include numerous bodies of leucogranite and aplogranite cutting the McLennan Group and locally rocks of the Central Metavolcanic and MacLean Lake Belts. Individual bodies are small plug- or sill-like masses ranging from a few tens of metres to several hundred metres wide and up to several kilometres in length. The leucogranites are typically medium grained, greyish pink to moderate pink and possess an equigranular texture. In contrast, the aplogranites are darker, varying from dark pinkish red to reddish orange, and have a fine-grained saccharoidal texture. Both varieties are generally massive to weakly foliated, except locally where intense cataclastic fabrics are present. Mafic minerals include biotite (1 to 5 percent) and muscovite (1 to 3 percent). Magnetite and ilmenite are readily visible in hand-specimen.

Bartlett Lake Dyke Suite

A suite of northwest-trending intermediate to mafic dykes cut most rocks in the western part of the area. These dykes do not intrude the McLennan Group nor do they appear to cut the polymictic psammopelitic metaconglomerates in the Berg - Cathro Lakes area. Individual dykes range from less than 1 m to 5 m in width and can be traced for 10 m or more along strike. They typically form sharply bounded linear sheets commonly with branching dykes and wedge-like apophyses. Rare xenoliths are generally subangular to subrounded and less than 10 cm across. Subtle decrease in grain size along the margins of many dykes suggests chilled contacts were developed. The dykes are typically fine-grained, pale green to dark greenish grey and weakly to intensely schistose. Hornblende (35 to 50 percent) occurs as skeletal poikiloblastic grains up to 1 mm in diameter or as aggregates of smaller subidioblastic crystals. Subidioblastic biotite laths (5 to 20 percent), less than 0.5 mm long, display a strong preferred crystallographic orientation. One specimen examined in thin section contains 3 to 5 percent disseminated tourmaline (var. schorlite) as small crystals, less than 0.1 to 0.25 mm diameter.

Pegmatite Dykes

Granitic pegmatites intrude most units but are particularly prevalent in the McLennan Group, where they range from pale pinkish grey to light red and commonly contain coarse muscovite books, barrel-shaped tourmaline crystals up to 5 cm long and feldspar crystals up to 10 cm in diameter. Two generations of pegmatite are distinguished in the McLennan Group, namely 1) syntectonic irregularly shaped bodies with gradational or diffuse margins, and 2) late to posttectonic tabular zoned bodies with discrete wallrock contacts. Pegmatites in the Central Metavolcanic and MacLean Lake Belt differ from those in the McLennan Group in that they more commonly contain coarse biotite books rather than muscovite and are quartz monzonitic to granodioritic in composition. Syn- to posttectonic granodioritic to tonalitic pegmatite bodies on the east side of Bielby and Hine Lakes range from a few metres to several tens of metres in width and up to a few hundred metres in length. These pegmatites are composed of euhedral plagioclase crystals with anhedral interstitial quartz and large biotite books up to 10 cm in diameter, and many show yellow uranium bloom (e.g., uranophane) on outcrop and fracture surfaces.

Structure

Several deformation events are recognized in the Bing Lake area, and all supracrustal and most intrusive rocks possess one or more related penetrative fabrics. The earliest (S_1) is well developed in the supracrustal rocks as a schistosity parallel to bedding (S_0). However, this early fabric is weaker in the plutonic rocks, occurring as a discontinuous gneissosity or fracture cleavage, essentially parallel to intrusion margins and to the S_1 fabric in the adjacent supracrustals. A northwest-trending tight to isoclinal antiform of

presumed F_1 age has been identified immediately south in the MacKay Lake area (M. Thomas, 1986).

A second generation planar fabric (S_2) commonly intersects the S_1 plane at a low angle. It appears as a penetrative schistosity in mafic rocks and as a fracture cleavage in quartzofeldspathic rocks. In part, the S_1 foliation is transposed into S_2, confusing the distinction of the two ages of structures. The S_2 foliation is axial planar to north-northeast-trending folds (F_2), which form doubly plunging, overturned, tight to isoclinal structures with moderately to steeply northwest-dipping axial planes.

The outcrop pattern to the south of the Haugen Lake Synform, which is cored by meta-arkoses of the McLennan Group, may be explained by fold interference involving F_1 and F_2 structures. The geological map for this area shows a discontinuous belt of mixed metavolcanic and metasedimentary rocks around the south end of McComb Lake[1], with meta-arkosic rocks occurring north and south of this belt (Fig. 2). Similarities between the two 'arkosic' sequences suggest they are probably the same stratigraphic unit repeated across a major F_1 north-northwest-trending closure cored by the McComb Lake mixed supracrustals. Complex fault structures cutting the F_2 fold closure may reflect strain hardening during the waning stages of the F_2 event.

Lewry (1986) identified a west-southwest-plunging upright antiform which refolds the southerly continuation of the F_2 Haugen Lake Synform (Fig. 2). Similarly oriented structures are not identified in the Bing Lake area but, if present, would equate with an F_3 event.

The western part of the area is cut by several major northwest-trending faults, primarily interpreted from topographic lineaments evident on aerial photographs but also indicated by cataclastic fabrics observed on the southwest shore of Bing Lake, west shore of Cathro Lake and east of Thornton Lake. The northwest-trending structures have a general periodicity of 1000 to 1500 m spacing and can be traced for as much as 7 km.

Northwest-trending faults with a general periodicity between 1000 and 1500 m locally offset the northwest-trending lineaments in the western part of the area. Rocks close to these north-south faults are locally submylonitic to mylonitic, and kinematic indicators suggest there is a dominant dip-slip component of movement.

Northeast-trending shear zones are recognized in the east of the area as localized zones of submylonitic to mylonitic fabric development and local microbreccia and coarse breccia. One series

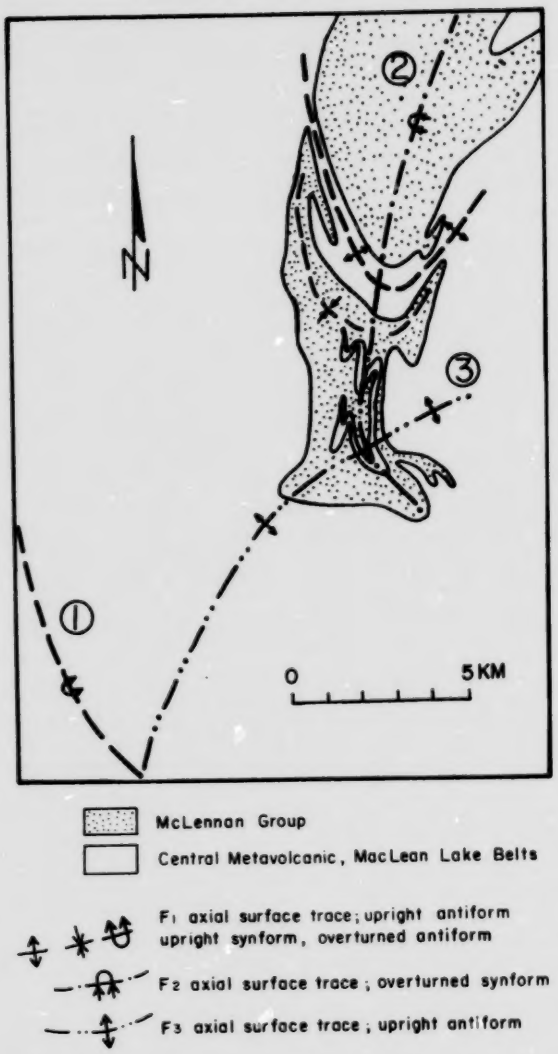

Figure 2 - Preliminary interpretation of major folds in the Bing-McKay Lakes area. Numbers refer to MacKay Lake Antiform (M. Thomas, 1986), Haugen Lake Synform (Padgham, 1960; Abraham, 1985; Thomas, 1987) and Mullock Lake Antiform (Lewry, 1986).

of anastomozing northeast-trending shears occur in a belt 3.5 km wide in the Althouse - Bielby Lakes area. This belt narrows to the northeast into a single shear structure extending along Woodhams Creek. Other major northeast-trending shear zones occur along the continuation of the Rattler Creek Fault through the Bergland Lake area, extending through the Dyer - Harlton Lakes area, and cutting the McLennan Group, possibly along a continuation or splay of the Stewart River Shear Zone (Abraham, 1985). The northeast-trending shear zones are interpreted as the latest major movement in the

[1]Previously referred to as Haugen Lake by Padgham (1960) and Abraham (1985).

area and may be temporally related to the McLennan lake Tectonic Zone to the north (Thomas, 1986).

Metamorphism

All rocks in the map area have been variably affected by regional metamorphism. Prograde mineral assemblages involving garnet, diopside, hornblende, epidote, biotite and muscovite indicate that lower to middle amphibolite conditions were attained across the area. This metamorphic grade appears to have been reached during the earliest (F_1) deformational event and was maintained to the end of the last major folding episode (F_2). Retrogression to greenschist facies conditions is indicated in the majority of the shear zones; however, preservation of stable hornblende in some sheared amphibolitic rocks indicates that higher metamorphic conditions were locally preserved during cataclastic deformation. Contact metamorphism may be indicated by dense amphibolitic rocks around the Bridgeman Lake Pluton.

Mineral Exploration

Previous mineral exploration activity identified no significant mineralization in the area except for a relatively small body of massive magnetite and pyrrhotite in the Bassett Lake area. No gold occurrences are known to have been found in the area to date. Exploration activity during the last year has been undertaken in the Bing Lake area by Silvera Resources Inc., and around Beranek Lake by Cogema Canada Ltd.

Iron-Nickel-Graphite, Bielby-Hine Lakes

A small diamond-drill program and ground electromagnetic survey was undertaken by Noranda Exploration Co. Ltd. in the late sixties in the Bielby and Hine Lakes area. Drilling intersected disseminated pyrrhotite, pyrite, graphite, and traces of chalcopyrite and arsenopyrite in a mixed assemblage of hornblende gneiss, biotite gneiss and calc-silicate rocks (Assessment File 73P10-0036, Saskatchewan Energy and Mines, Regina). Follow-up work was not considered warranted.

Bassett Lake Iron Anomaly

Massive iron oxide and lesser iron sulphide mineralization occurs along the west side of Triangle Lake located about 1000 m southeast of Bassett Lake in metagabbroic to metanoritic rocks of the Bassett Lake Intrusion. The deposit was investigated in considerable detail between 1954 and 1968, resulting in preliminary reserve estimates in the order of 27 million tonnes averaging 20 percent Fe (Harper, 1983). The mineralized body is 900 m long, 60 m wide and 150 m deep. Mineralization occurs as titaniferous magnetite, forming 5 to 60 percent of the rock, which locally contains up to 20 percent pyrrhotite.

Copper, Berg-Cathro-Welk Lakes

Regional mapping by the Saskatchewan Geological Survey in 1959 (Padgham, 1960) identified a number of areas with small amounts of copper mineralization in a belt of trachytic intermediate metaflows between Milner and Welk lakes. Follow-up investigations by industry were not encouraging (Assessment Files 73P10-0072, 73P10-0047).

Suggestions to Explorationists

The Bing Lake area lies in the same lithostructural belt which hosts significant gold deposits to the north (e.g., Star - Waddy Lakes area) and to the south (e.g., Sulphide - Preview Lakes area); consequently, the potential for precious metal discoveries should be high. A number of areas warrant further evaluation for gold as well as other metals (numbers in parentheses refer to locations of areas illustrated in Fig. 1):

Thornton-Bartlett Lakes (1): North-trending shear zones cutting rocks of the Bartlett Lake Intrusion commonly contain narrow quartz veinlets with traces of chalcopyrite, pyrite and pyrrhotite. These small-scale quartz veinlets may be indicative of larger sulphide-bearing quartz vein systems elsewhere along these shear zones.

McComb Lake (2): At the south end of a small lake 750 m southwest of McComb Lake, disseminated sulphides occur in a quartz-cemented fault breccia incorporating previously sheared meta-arkosic rocks. The breccia is developed along a major northeast-trending structure extending for about 12 km towards Otter Lake. The presence of early submylomitic fabrics, late brittle fractures, local quartz flooding and sulphides presents a promising exploration target.

Bridgeman Lake (3): A number of gossan zones are found in sheared amphibolitic and calc-silicate gneisses in the eastern part of the area. The gossans contain variable amounts of pyrite, pyrrhotite, chalcopyrite and locally arsenopyrite. The most prominent of these gossans occur 1) at the south end of a small lake located 1100 m north of Bergland Lake, 2) 1600 m north-northeast of Dyer Lake, and 3) in a small outcrop at the southwest end of Bousfield Lake. The presence of arsenopyrite and small quartz veins in these gossans is somewhat similar to the gold mineralization in the Sulphide Lake area.

Berg-Cathro Lakes (4): Disseminated sulphides occur in mixed metatrachytic flows and

metasediments in the Berg - Cathro Lakes area. This assemblage has previously been explored for copper but its gold potential has not been adequately evaluated and merits further attention. Exploration by Silvera Resources Inc. along the northern continuation of this belt, at Wapiyao Lake, has identified significant gold values in sheared quartz veins containing arsenopyrite and pyrite (Thomas, 1986).

Welk Lake (5): Small quartz-filled tension gashes occur locally in sheared rocks along northwest-trending structures cutting the Welk Lake Pluton. The presence of locally sheared intermediate to mafic dykes and shear-related quartz veins presents a somewhat similar setting to that at Star Lake.

Althouse Lake (6): Metavolcanic and metasedimentary rocks rich in magnetite extend through the Althouse - McComb Lake area. The magnetite occurs as finely disseminated grains, forming up to 5 percent of the rock, and in massive branching veinlets. Magnetite content is commonly higher in the more strongly foliated to sheared rocks. Anomalous concentrations of magnetite may indicate enrichment in other metals (e.g., gold, zinc, lead, copper).

Bing Lake (7): Disseminated sulphides occur in intermediate to mafic dykes in the western part of the area. One dyke on a small island in Bing Lake contains coarse molybdenite flakes in late crosscutting quartz veins. As the high concentration of dykes between Bing and Bartlett Lakes may have been conducive to generating local hydrothermal systems which could extract and concentrate metals from the country rocks, evaluation of these dykes may be worthwhile.

McLennan Group (8): The meta-arkoses of the McLennan Group have not previously received much attention as a site for potential economic mineralization. Magnetite- and ilmenite-bearing beds, present locally throughout meta-arkoses and generally less than a metre thick, may reflect sedimentary heavy mineral concentrations. Concentration of other elements, such as rare earth elements and gold, through a paleoplacer model within the McLennan Group is somewhat speculative, but may merit consideration.

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Project 8730

Bedrock Geological Mapping, Pine Channel Area (Part of NTS 74O-7 and -8)

by W.L. Slimmon and R. Macdonald

Slimmon, W.L. and Macdonald, R. (1987): Bedrock geological mapping, Pine Channel area (part of NTS 74O-7 and -8); in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

The Pine Channel area, at the east end of Lake Athabasca, was geologically remapped at a scale of 1:20,000 this summer in order to provide more detailed geological information in a region of known gold occurrences. Coombe (1984) identified the region as a "priority 2" area for gold exploration in Saskatchewan, and there has been industry interest in the area of late.

Gold occurs north of Pine Channel in Precambrian gneisses of the Tantato Domain (Gilboy, 1980). The mineralization is generally found in crosscutting sulphide-bearing quartz veins which infill local shears and fractures associated with regional shear/fault lineaments (Fig. 1). The quartz veins are largely restricted to an 8 km wide belt of east-northeast-trending garnet-hypersthene felsic gneisses and mafic pyroxene gneisses, which are referred to here as the Pine Channel Assemblage.

The mapped area covers about 200 km^2 and extends from Pine Channel north to Grease River. The area is accessible by boat or float plane from Stony Rapids, about 45 km to the east. Surface topography comprises east-northeast-trending rocky ridges and valleys with local relief up to 100 m. Bedrock exposure is excellent except northwest of Robillard Bay and along the Grease River where Quaternary glaciofluvial outwash plain deposits are encountered (Schreiner 1984).

Previous geological mapping covered the region at scales varying between 1:253,440 and 1:18,000 (Alcock, 1936; Mawdsley, 1949; Colborne and Rosenberger, 1963; Baer, 1969; Colborne, 1982 (based on work done in 1963)). The area is also included in a preliminary 1:250,000 scale compilation map of the Fond-du-Lac area (map in accompanying package).

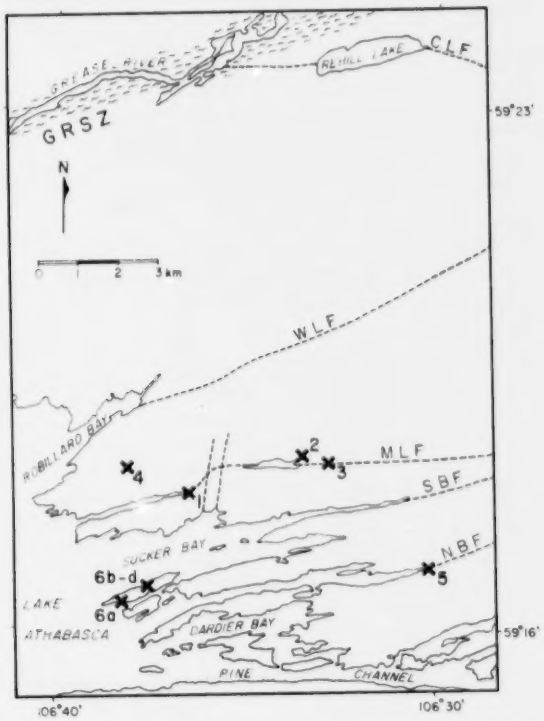

Figure 1 - Location map of major shears/faults and gold showings, Pine Channel area. GRSZ, Grease River Shear Zone; CLF, Clut Lakes Fault; WLF, Wiley Lake Fault; MLF, Malinoski Lake Fault; SBF, Sucker Bay Fault; NBF, Norite Lake Fault. The Pine Channel Assemblage lies generally south of the Wiley Lake Fault. Gold showings indicated by numbered crosses: 1, Mel-Cec; 2, Ela; 3, occurrence no. 5; 4, occurrence no. 9; 5, occurrence no. 10; 6a-d, Thompson Island showings.

Regional Geology

The Tantato Domain is bounded to the northwest and east by the Grease River and Black Lake Shear Zones respectively, and to the south by Lake Athabasca and the Fond-du-Lac River. Regional aeromagnetic maps suggest that the southern boundary, which projects under the Athabasca Basin along Pine Channel, may also be shear zone bounded.

The Pine Channel Assemblage, which lies generally south of the Wiley Lake Fault (Colborne, 1962) (Fig. 1), comprises garnetiferous felsic gneisses interlayered in places with mafic pyroxene gneisses (some previously described as "norite"), iron formation and local quartzite. According to Colborne (1960), the assemblage occupies the core

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of a regional synform which plunges at low angles to the southwest. We believe the Pine Channel Assemblage to be derived from 'greywacke' basin sediments with associated intermediate to mafic volcanics and paravolcanic intrusions.

The Pine Channel Assemblage is retrogressively metamorphosed to the north, and gives way to biotitic gneisses which show progressively lower grades and increasing deformation towards the Grease River. These northern rocks are referred to here as the Grease River Assemblage. Described previously as biotite gneisses (Colborne, 1963, 1982), our mapping shows that the assemblage comprises some supracrustal rocks, but mainly plutonic rocks which have been variously sheared, mylonitized and largely subjected to postkinematic annealing and blastic recystallization. Hanmer (1986) has described rocks farther northeast in the Tantato Domain as mylonites derived from plutonic rocks.

Pine Channel Assemblage

Garnetiferous Felsic Gneisses (Unit Qf):

The commonest rock type in this assemblage, these rocks are generally fine to medium or locally coarse grained with creamy white to light grey to brownish-grey weathered surfaces. Garnet occurs as porphyroblasts of variable size, averaging 2 to 4 mm in diameter, and as garnet-quartz aggregates up to 5 cm in diameter in amounts up to 30 percent of the rock, although some layers and lenses contain as much as 80 percent garnet in a siliceous groundmass. The garnet is usually at least partially retrogressed to biotite. Towards the north and west, weathering of the biotite has produced pock-marked surfaces. Biotite comprises up to 30 percent of the rock. Quartz (typically 20 to 25 percent) is streaked or ribboned in many places and shows a bluish tinge where the rock is retrogressed. Hypersthene porphyroblasts occur locally, in places reaching 3 cm in size, and sillimanite and graphite are present in trace amounts. Conformable 'quartzitic' layers and lenses up to 30 cm wide, consisting of almost 100 percent quartz, occur locally.

The unit is generally strongly layered and on the mesoscopic scale typically quite heterogeneous, comprising more mafic garnetiferous and biotitic layers alternating with more feldspathic layers. Anatexis and migmatization locally overprint, and in places the gneisses have a more uniform appearance suggestive of magmatic rocks, especially along the northern part of the assemblage and southeast of Norite Bay. North of the Malinoski Lake Fault (Fig. 1), white medium-grained tonalitic neosome sweats are common.

Throughout this unit, posttectonic quartz veins of variable widths trend predominantly northwest to north, although conformable veins are also present.

Mafic Pyroxene Gneisses (Unit M):

Subconcordant layers of pyribolite/amphibolite ranging in width from a few millimetres up to 100 m, are commonly intercalated with unit Qf rocks. These generally fine-grained rocks vary from dark grey to dark green, and where garnet is prolific have a purplish tinge. Hypersthene and diopside are the dominant mafic minerals, except where hypersthene is retrogressed to hornblende. Garnet (up to 30 percent) is usually fine grained (1 to 2 mm). The unit contains numerous conformable gossanous zones containing disseminated pyrite and pyrrhotite.

In general these mafic rocks are less retrogressed than the contiguous felsic gneisses. On the north shore of Dardier Bay ovoid pillow-like structures up to 50 cm long were observed. These structures, together with textural features and the intercalated nature, suggest derivation predominantly from intermediate to mafic tuffs, mafic flows and high level sills.

Iron Formation (Unit IF):

Silicate-facies iron formation occurs in the southeast in layers composed of up to 80 percent garnet and abundant magnetite. Several other locations in this region contain interlayered garnetite layers with traces of magnetite.

Pegmatite (Unit Peg)

Two types of pegmatite were noted cutting the garnetiferous felsic gneiss:

1) Conformable to obliquely crosscutting pegmatites observed on the north shore of Dardier Bay have been variously foliated and deformed. These pegmatites are intratectonic, as they have been involved in regional granulite facies metamorphism and subsequent retrogression together with the contiguous gniesses.

2) An outcrop of sharp-walled posttectonic pegmatite east of Dardier Bay contains feldspar crystals up to 6 cm long.

Grease River Assemblage

Pre-cataclastic Rocks:

Although most rocks in the Grease River Assemblage are mylonitized to some degree, lenses up to 300 m wide of relatively undeformed plutonic rocks occur throughout, together with some rocks of apparent supracrustal origin. There is normally a transition into the mylonitic rocks over a distance of a few metres, but locally as little as a few centimetres.

The pre-cataclastic rocks of the Grease River Assemblage are divided into granite (unit Gr), granodiorite (unit Gd), quartz diorite (unit Qd) and quartz monzonite (unit Qm). Biotite is ubiquitous to all units, averaging 5 to 10 percent of the mode. Hornblende occurs in most units, primarily as porphyroblastic grains up to 5 mm in size or replacing garnet. Garnet porphyroblasts up to 5 mm in diameter occur chiefly in the hornblendic rocks. The granite cuts the other units in concordant sheets a few millimetres to several metres wide.

Cataclasis affects all of these rocks; textures vary from very fine grained, banded 'zebra' mylonites to augen gneisses with tightly packed lensoid augens to uniformly fine-grained rocks with sporadic oval or even round augens ranging from 2 to 70 mm in size. Although some of the augens are single feldspar crystals, the majority comprise feldspar and quartz-feldspar aggregates and less commonly quartz and/or amphibole aggregates or single crystals. Many of the rocks with sporadic rounded augens lack lineated fabrics, and the fine-grained matrix displays little evidence for mylonitization per se. These features are ascribed in part to postkinematic recrystallization and blastesis. Medium-grained cataclasites, on the other hand, are commonly strongly lineated. Despite these observations, the possibility remains that some of the rocks with sporadic augens may have derived from supracrustal precursors, including tuffs.

Post-cataclastic Rocks:

Psammopelitic gneiss (unit P) outcrops in synformal structures in the northern part of the assemblage. These fine-grained light grey to brownish rocks, which appear to be relatively undeformed, have a granular texture and typically possess rudimentary to well developed banding, but are weakly migmatized locally. Biotite averages 5 to 10 percent. Accessory garnet, muscovite, sillimanite and rare cummingtonite occur locally.

A massive to slightly foliated diorite intrusion (unit Di) north of Melby Lake displays a coarse centre with a progressively finer grained margin. Black to very dark green hornblende is conspicuous, averaging 25 to 30 percent of the rock and locally as much as 60 percent. The rock contains accessory biotite and diopside, as well as local garnet 1 to 2 mm in diameter. Anorthosite (unit An) occurring in the centre of the intrusion is a coarse- to very coarse grained creamy white rock composed almost entirely of plagioclase with accessory biotite, hornblende and garnet.

Muscovite granite (unit Gm) underlies the extreme northeastern corner of the area. This posttectonic, massive to very weakly foliated rock comprises a mixture of medium- to coarse-grained granite and coarse-grained granitic pegmatite. Biotite and muscovite each average 2 to 3 percent of the granite and garnet occurs sporadically. Near the contact at Rehill Lake, the granite occurs as conformable and crosscutting injections into schistose mylonitic rock. Chilled margins up to 4 cm wide have been observed in these injections. Quartz masses and veins, locally containing tourmaline but lacking any sulphide mineralization, are dispersed throughout the granite.

Structural Geology

The map area comprises the western part of a major synform which plunges at shallow angles to the southwest. Regional gneissosity (layering) strikes east to slightly north of east and has a dominant steep southerly dip, denoting general overturning to the north. Isoclinal folds which occur throughout the area are generally congruent with the regional fold style. Mineral lineation and rodding coaxial to this folding typically plunge at low angles to the west-southwest, except in the area between the Sucker Bay and Wiley Lake Faults (Fig. 1) where they plunge to the east.

North of Robillard River open to tight folds on similar trends have wavelengths of approximately 0.5 to 1.5 km. In places the synformal troughs of these folds are occupied by unit P psammopelitic gneisses.

The Grease River Shear Zone occupies an erosional valley up to 1.5 km wide along the northern margin of the map area. Mylonites of this zone have schistose textures produced by lower grade reworking of the previously mylonitized rocks of the Grease River Assemblage.

Several major lineaments, possibly products of shearing/faulting along northeast-southwest fold limbs, parallel the regional gneissosity, resulting in narrow ridges and valleys. The Wiley Lake Fault and Sucker Bay Fault are two of the more prominent faults of this type in the area. The terrain between the two faults possibly underwent some dextral rotational movement to the northeast which could account for the uncharacteristic northeasterly-plunging mineral lineations present here.

Major crosscutting fault lineaments trend predominantly west to northwest, and north. A continuation of the Clut Lakes Fault (Colborne, 1960) from the east crosses the area in the northeast corner (Fig. 1) and terminates at the Grease River Shear Zone. Johnston (1963) identified a relative dextral movement at one location along this fault east of the map area. Relative dextral movement along faults which parallel this fault in the present area apparently offsets the hinges of the broad open to tight fold system present in the northern zone. Smaller scale shears and fractures trend principally northwest to north and have both dextral and sinistral senses of movement, as exhibited by fault offsets and drag folding.

Metamorphism

All rocks in the area north of Pine Channel have been regionally metamorphosed. South of the Wiley Lake Fault, the sporadic occurrence of hypersthene in the felsic gneisses and more abundant hypersthene and diopside in the mafic gneisses indicate granulite facies conditions were attained. Regional amphibolite facies retrogression produced widespread replacement of hypersthene by hornblende and biotite, and of garnet by biotite.

Hypersthene does not occur north of the Wiley Lake Fault. In this area the mineral assemblage garnet, muscovite and sillimanite in the psammopelitic rocks, and retrogression of garnet to hornblende indicate that middle to upper amphibolite facies conditions prevailed. Throughout the map area local greenschist facies retrogression, especially in the vicinity of shear zones, is indicated by the chloritization of biotite.

Economic Geology

Mineral exploration has been essentially restricted to the Pine Channel Assemblage. Early exploration focused mainly on Ni-Cu mineralization associated with the mafic pyroxene gneisses (unit M). These rocks commonly contain pyrrhotite- and pyrite-bearing concordant gossanous zones, but nothing of economic value was discovered. It is not clear when gold was first discovered in the area, but in the mid-thirties several companies carried out exploration programs which led to the discovery of a number of gold occurrences. This activity has continued sporadically with a slight increase in intensity in the last few years. Several of the gold occurrences also contain elevated silver values. Uranium was discovered in the area in 1950, but despite several exploration programs economic deposits have not been discovered.

Uranium

In 1950, Goldfields Uranium Mines Ltd. discovered a radioactive occurrence southeast of Algold Bay (UTM co-ordinates 408420mE, 6573600mN) while prospecting for gold,. Disseminated grains and veinlets of pitchblende occur in a set of three parallel near-vertical hematized fractures striking 295-305°. Although one grab sample assayed 7.22 percent U_3O_8, most other grab and drill core samples assayed less than 1 percent U_3O_8. The radioactive fracture zones which are up to 0.5 m wide have been traced along strike for 125 m and to a depth of 80 m (Assessment Files 74007-0007, -0022, Saskatchewan Energy and Mines, Regina).

Gold and Silver

All known gold occurrences in the map area are located south of the Wiley Lake Fault. They are primarily fracture-fill type deposits with quartz partially or wholly infilling predominantly northwest-striking fractures and shears which crosscut the garnetiferous felsic gneisses (unit Qf). The mineralized fractures and shears are generally associated with the major northeast-trending fault lineaments. Tourmaline, pyrite and arsenopyrite are typically associated with the gold occurrences. Beck (1959) and Coombe (1984) summarized the geology and history of exploration of the major gold showings in the area. Major showings visited by one author (W.L.S.) are summarized below. Numbers in parentheses after the occurrence names correspond to locations on Fig. 1.

Mel-Cec Showing (1): At the east end of Algold Bay (UTM co-ordinates 408300mE, 6574060mN), two parallel fracture zones 4 to 5 m apart are occupied by quartz veins striking 315° and dipping 85° northeast. The veins, which average 40 cm wide, contain massive and disseminated arsenopyrite and pyrite. The northernmost fracture zone exhibits an apparent dextral movement. Early work on the showing included trenching, which traced the vein system for a strike length of 300 m. Channel sampling by Golden Rule Resources Ltd. in 1980 returned assays up to 0.85 oz./ton Au over 0.58 m and 0.56 oz./ton Ag over 0.6 m (Assessment File 74007-0046). Visible gold was reported in the northeast vein.

Ela Showing (2): Northeast of Malinoski Lake (UTM co-ordinates 411100mE, 6575040mN), several trenches and a 10 m deep shaft have exposed a subvertical quartz-filled shear system striking 315° which can be traced for approximately 240 m. The quartz vein is typically 30 to 40 cm wide, but widens to 4 m locally. The vein is commonly vuggy in the wider zones where euhedral quartz up to 3 cm long is present. Mineralization within the vein comprises disseminations, veinlets and masses of pyrite and arsenopyrite. Work done in the fifties suggested the presence of a gold-bearing shoot near the shaft that averages 0.51 oz./ton Au over a width of 1.2 m and length of 36.6 m (Coombe, 1984). Sampling by Golden Rule Resources Ltd. in 1980 extended this length to a minimum of 95 m and indicated the possible existence of a second shoot near the northernmost two trenches. Silver values up to 1.18 oz./ton over 0.5 m were also obtained (Assessment File 74007-0046).

Occurrence No. 5 (3): Located 700 m east of Malinoski Lake (UTM co-ordinates 411800mE, 6574740mN), this showing comprises a series of trenches and a shallow shaft along a quartz vein/shear system that strikes 300° and dips 80° northeast. The shear zone, which has a possible dextral sense of movement, averages 1 m wide but locally the wall rocks are brecciated for up to 2 m on each side of the zone. The quartz vein, up to 50 cm wide, contains disseminated and massive arsenopyrite and pyrite. A grab sample from the massive arsenopyrite assayed 0.2 oz./ton Au (Assessment File 74007-0046). A second vein

branches off the main system 25 m northwest of the shaft, but mineralization is not as abundant.

Occurrence No. 9 (4): Between Robillard and Algold Bays (UTM co-ordinates 406860mE, 6574780mN), trenching and drilling have uncovered a vertical quartz vein striking due north which has been traced for at least 200 m. The vein, which averages 0.1 to 2.5 m wide, is in contact with pyribolite to the west and biotite-quartz-feldspar gneiss to the east. Mineralization includes disseminations, veinlets and masses of arsenopyrite and pyrite as well as disseminated chalcopyrite at one locality. Grab samples assayed up to 0.48 oz./ton Au and 0.44 oz./ton Ag (Assessment File 74O07-0047).

Occurrence No. 10 (5): Three old trenches at the east end of Norite Bay (UTM co-ordinates 414280mE, 6572070mN) expose a northeast-dipping quartz vein system 10 to 30 cm wide striking 310°. The vein system crosscuts a ridge possibly formed by parallel northeast-trending major shear zones. Disseminated and massive arsenopyrite mineralization is typical and several percent disseminated galena is present in one area. A grab sample assayed 0.16 oz./ton Au, 0.44 oz./ton Ag and 0.58 percent Pb (Assessment File 74O07-0046).

Thompson Island Showings (6): From 1979 to 1981, Kintla Explorations Ltd. in joint venture with SMDC carried out an extensive exploration program on Thompson Island. The program identified several zones of significant gold and silver mineralization, but assay results were conflicting and nonreproducible. Thompson Island is bounded to the northwest and southeast by two regional offshore faults which are connected by two main sets of cross-faults trending north and northwest respectively. Gold and silver mineralization is primarily associated with quartz veins in the north-trending fault set and, to a lesser degree, silver mineralization is associated with the northwest-trending faults. Mineralization is also controlled by the presence of arsenopyrite and tourmaline. Areas with the most significant mineralization include:

(6a) (UTM co-ordinates 406540mE, 6571420mN): Trench samples from an arsenopyrite-tourmaline mineralized quartz vein near the south shore at the west end of the island assayed up to 8.22 oz./ton Au over 25 cm and 2.54 oz./ton Ag over 15 cm (Assessment File 74O07-0045). The vein, which strikes parallel to the local gneissosity but dips to the north rather than the south, originates from a north-trending fault zone which displays apparent sinistral movement.

(6b) (UTM co-ordinates 407270mE, 6571800mN): Near the middle of the island's north shore, brecciated quartz veins with arsenopyrite and pyrite mineralization occupy a subvertical fracture zone striking 005°. Drag-folding of the wall rocks indicates a sinistral shear sense of movement. Visible gold is reported and trench samples assayed as high as 4.2 oz./ton Au over 60 cm and 1.94 oz./ton Ag over 60 cm (Assessment File 74O07-0045).

(6c) (UTM co-ordinates 407355mN, 6571820mN): Approximately 85 m west of the above showing, a trenched area approximately 35 m long extends westerly from a north-trending shear zone which dips steeply to the east. The trench exposes a quartz vein system, with massive sulphide mineralization comprising arsenopyrite, pyrite and jamesonite, which is nearly concordant to the local gneissosity. Drill core records report the presence of acanthite and one trench sample assay over 1.8 m returned values as high as 1.04 oz./ton Au, 171.9 oz./ton Ag, 10.39 percent Sb and 19.72 percent Pb (Assessment File 74O07-0045).

(6d) (UTM co-ordinates 407355mE, 6571720mN): About 120 m south of occurrence 6c, the north-trending shear zone contains arsenopyrite and pyrite mineralization in a brecciated quartz vein. Drag-folding of the surrounding rocks both here and at the shore indicate sinistral fault movement. Visible gold is reported and trench samples assayed up to 5.6 oz./ton Au over 1.5 m (Assessment File 74O07-0045). On the west side of the shear zone, a quartz vein containing visible gold off-shoots nearly concordant to the local gneissosity.

Recommendations for Further Prospecting

In addition to the showings described above, several other zones of sulphide mineralization in the map area are shown on the accompanying geological map. As several gold showings and areas of sulphide mineralization occur in close proximity to the northeast-trending major fault lineaments, it is recommended that further work be carried out along their northeasterly extensions. The two most obvious of these extended areas are along the Malinoski Lake and Norite Bay Faults (Fig. 1). Other areas that warrant further inspection include the relatively less explored area east of Dardier Bay and around Camille Bay where the previously-mentioned iron formations occur.

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Project 8733

Bedrock Geological Mapping, Campbell River Area (Part of NTS 64E-6)

by D.G. MacDougall

MacDougall, D.G. (1987): Bedrock geological mapping, Campbell River area (part of NTS 64E-6); in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

The purposes of this project are to 1) investigate the syenogranite intrusion noted by Lewry et al. (1980) for undersaturated phases with REE and rare metal potential; 2) integrate the results of previous work on the Campbell River Group metasediments, which host stratabound zinc-iron mineralization, with supplementary detailed mapping and sampling; and 3) establish the relationship of the Campbell River Group to the surrounding rocks.

The area is one of gentle to moderate relief, bordered on the northwest by flatter drift and muskeg-covered ground.

The Campbell River Group occupies a narrow canoe-shaped northeast-trending belt, up to 2 km wide and 19 km long, near the southeast margin of the Peter Lake Domain. The belt correlates with a pronounced magnetic low of less than 3500 gammas (Geological Survey of Canada, 1963), which extends southwestwards beyond the limits of the map area, possibly indicating reappearance of the metasediments further along strike in this direction.

PREVIOUS WORK

The Campbell River Group metasediments were discovered by the Don Fisher Syndicate in 1967 during follow-up work to an earlier airborne EM/magnetic survey (Fisher, 1967). Subsequent work between 1970 and 1973 by Buval, Boswell River and Canol Mines Ltd. (Leask, 1969; Parent, 1970; Lintott and Pyke, 1971), Husky Oil Ltd. (Pyke and Lintott, 1971), Husky Oil Operations and Canol Mines Ltd. (Pyke and Lintott, 1972; Lintott and Pyke, 1972) and Candel-Husky Oil Operations Ltd. (Dublonko and McPherson, 1973) outlined the extent and character of the metasediments, the nature of their contacts with surrounding rocks and their geophysical characteristics. Interest in the area was spurred by the discovery of extensive stratabound zinc-iron sulphide mineralization in pelitic members of the succession. Most recently the area has been held under a large permit by Lacana Mining Corp., which was investigating the basic and ultrabasic rocks of the Peter Lake Domain for platinum potential.

Project funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

The Campbell River metasediments were investigated during reconnaissance mapping by Lewry and others who raised them to group status (Lewry, 1976; Lewry et al., 1980).

GENERAL GEOLOGY

The Peter Lake Domain is a shear-bounded block separated from the Wathaman Batholith to the southeast by the Parker Lake Shear Zone and from the Wollaston Domain to the northwest by the Needle Falls Shear Zone. Large areas of the domain and its boundaries are blanketted by thick glacial overburden, obscuring the interrelationship of rock types.

Lewry (1976) recognized the presence in the Peter Lake Domain of an older dioritic-gabbroic suite containing metavolcanic and metasedimentary inclusions, intruded by syenomonzonitic and granitic plutons. The Campbell River Group and other supracrustal relicts in the Peter Lake Domain were interpeted as remnants of an oceanic volcanosedimentary assemblage.

Early interpretations of the age of the domain rested on indirect evidence such as the low degree of deformation of the felsic plutonic rocks, from which it was inferred that they were broadly coeval with the relatively undeformed Wathaman Batholith of Aphebian age (i.e., ca. 1850 Ma) (Lewry, 1976). Ages obtained by Ray and Wanless (1980) on a sample of meta-quartz diorite within the Parker Lake Gneisses and by Van Schmus et al. (1987) from a sample of granitoid show that some components of the domain are older than 2500 Ma. An Archean age has been tentatively attributed to the Campbell River Group on the basis that rocks similar to the sample dated by Ray and Wanless contain xenoliths of inferred Campbell River metasediments (Macdonald and Thomas, 1983).

The present study recognizes two main assemblages: 1) the Peter Lake Complex, comprising felsic plutonic rocks (in part intrusive and in part forming presumed basement to the Campbell River metasediments), and 2) the Campbell River Group, comprising metasediments and intrusives. The Lyle Lake Pluton, occurring within the Peter Lake Complex, is a postdeformational concentric annular intrusion. The sequence of intrusion apparently commenced

with the coarse-grained granite (surviving now only as a discontinuous envelope), progressed through increasingly more alkaline stages to form the ring of quartz syenite, and concluded with the core of fine-grained granite and marginal apophyses and dykes of aplitic syenite. Lamprophyre sills, which crosscut foliation in the Campbell River Group and are in turn cut and displaced by north-trending tear faults, are possibly contemporaneous with the Lyle Lake Pluton. Tentative relationships between rock types, established by crosscutting intrusive, xenolithic and stratigraphic evidence, are set out in Table 1.

LITHOLOGIC UNITS

Peter Lake Complex

Representative modal compositions of rocks from the Peter Lake Complex are listed in Table 2.

Felsic Plutonic Rocks of Presumed Campbell River Basement (Unit 3):

Quartz syenomonzonite (unit 3) is widespread, surrounding the Lyle Lake Pluton and forming the

Table 1 - Table of Lithologic Units

PERIOD	MAJOR GROUPING	SUBDIVISIONS	ROCK TYPES AND RELATIONSHIPS	ROCKS OF UNCERTAIN AFFINITY OR ORIGIN
PLEISTOCENE			Glacial moraines, tills and fluvioglacial outwash	
			----------MAJOR UNCONFORMITY----------	
?HUDSONIAN	PETER LAKE COMPLEX	LATE STAGE INTRUSIVE SYENOGRANITIC ROCKS	Aplitic syenite (1a)) IN PART Fine-grained granite (1c)) THE LYLE Quartz-syenite (1b)) LAKE Coarse-grained granite (1d)) PLUTON ---RELATIONSHIP UNCERTAIN---- Porphyritic alkali-feldspar syenite (1e)	Mafic dyke rocks (6) White syenite (7a) White syenitic pegmatite (7b)
			--INTRUSIVE CONTACTS----------	
		INTERMEDIATE STAGE INTRUSIVE PLUTONIC ROCKS	Quartz-monzonite (2) Adamellite (3a) Quartz-monzodiorite (4a, 4b) Tonalite (4c)	Foliated granitoid (17) (tectonized equivalent ?)
			---RELATIONSHIP UNCERTAIN----	
?APHEBIAN	CAMPBELL RIVER GROUP	INTRUSIVES IN THE CAMPBELL RIVER GROUP	Feldspar mica lamprophyre (5a) Mica amphibole lamprophyre (5b) Fine-grained mica amphibole lamprophyre (5c) ---RELATIONSHIP UNCERTAIN---- Quartz-diorite (13)	Carbonate rock (8) Mica amphibolite (14) Hornblendite (16)
			---INTRUSIVE CONTACTS----------	
		CAMPBELL RIVER GROUP METASEDIMENTS	Pelite (12a) Amphibolite (15a) Calc-pelite (12b) Anthophyllite amphibolite (15b) (225 m) Amphibolitic epiclastic (15d) (150-325 m)	Meta-arkose (18)
			CONFORMABLE CONTACTS FACIES EQUIVALENTS	
			Sulphidic mudstone (11)) Slatey argillite (10a)) ---METAMORPHIC EQUIVALENTS----) (200 m) Meta-argillite (10b)) Chloritic phyllite (10c))	
			CONFORMABLE CONTACTS	
			Quartzite (9a) Banded calc-silicate quartzite (9b) Amphibolitic calc-silicate (15c) (100 m) (75 m) (75 m)	
			--OVERTHRUST UNCONFORMITY?----------	
?ARCHEAN	PETER LAKE COMPLEX	FELSIC PLUTONIC ROCKS OF PRESUMED CAMPBELL RIVER BASEMENT	Quartz-syenomonzonite (3)	

Table 2 - Modal Compositions of Felsic Plutonic and Other Intrusive Rocks

UNIT NUMBER	1a	1b	1c	1d	1e	2	3a	4a,b	4c	3		6	7a	7b
MINERAL %														
K-SPAR	80	55	45	50	70	25-54	35	12-25	5	43-90			70	70
PLAGIOCLASE	15	15	15	20	8	27-45	20	33-55	60	0-28		35-40	20	25
QUARTZ	5	20	25	30	2	15	30	5-7	15	3-22				
BIOTITE	tr	2	5	7	10	0-5	10	15-23	15	0-3		15-20	5	1
CHLORITE	tr						5			0-20				
MUSCOVITE		tr			3	tr								1
AMPHIBOLE	tr		7	3		0-5		2-15	7	0-3		40-50		
PYROXENE						0-5								
FLUORITE		2				tr							<1	
CARBONATE					1	<1-5	<1		tr	0-5				
SPHENE			<1					tr						
ZIRCON			tr											
EPIDOTE			<1	2			2	1-3	3	0-2		tr		
APATITE					1	tr	tr	<1-1	<1	tr			<1	
OPAQUE	<1	tr	1	3	7			tr		tr				1
LEUCOXENE	tr													
SODALITE													2	
ANALCIME													tr	

major marginal phase in contact with or near to the Campbell River Group, as well as approximately round masses.

The rock is coarse grained, foliated to unfoliated, nonporphyritic, salmon pink to pinkish grey and made up of 30 percent combined chlorite, biotite and amphibole (as 5 to 8 mm clots of fine grains), brick red to pink potassic feldspar, mottled pale pink to white plagioclase and traces of pyrite. In strongly foliated varieties the biotite is smeared around composite 'eyes' of felsic minerals, producing an augen texture. Garnetiferous zones are present at the contact with quartzites (unit 9) north of Campbell Lake, and elsewhere there are a few aplitic patches, and small quartz pods.

Xenoliths are quite common, occurring as 1 to 2 cm mafic vein-like inclusions, 30 cm fine-grained dark grey biotite-rich streaks, veinlets and clots (all probably derived from pelitic metasediments), and locally abundant 3 to 30 cm egg-shaped xenoliths of plutonic meta-igneous rocks, mostly tonalite and porphyritic micromonzonite. South of Inhospitable Lake, large rafts of foliated, partially assimilated quartzite containing elongate aggregates of magnetite (90 percent) up to 3 by 15 cm, with some biotite and 1 percent disseminated pyritohedral pyrite, have contaminated the host rock, locally changing its composition to that of a quartz-rich adamellite.

Intermediate Stage Intrusive Plutonic Rocks (Units 2, 3 (in part) and 4:

Quartz monzonite (unit 2) occurs as small subcircular intrusions along the contacts of the Campbell River Group, as a submarginal phase separated from the Campbell River Group by quartz syenite (sheared and intrusive contacts) and in intrusive contact with tonalite.

The rock is medium to coarse grained, foliated, pink weathering and greyish pink on fresh surfaces, and consists of pink and grey feldspar, 25 percent combined amphibole, chlorite and biotite (as 8 mm clots of grains less than 1 mm in size), and traces of pyrite. Fluorite veinlets are present in one sample from the Lyle Lake area. Inclusions are common, especially in the intrusion northeast of Campbell Lake, where there is a profusion of randomly oriented angular, elliptical and round plutonic meta-igneous xenoliths of both monzonitic and tonalitic affinity.

Adamellite (subunit 3a) is confined to an area north of Hornfels Lake near the contact with quartzites (unit 9). It is a coarse-grained foliated grey rock with white to grey feldspar, in part showing green saussuritized cores, quartz and 20 percent biotite. Examples with pronounced foliation are augen textured.

Quartz monzodiorite (subunits 4a and 4b) occurs as a marginal phase to the Campbell River Group and as a medium-sized oval intrusion east of Hornfels Lake.

The rock is coarse grained, light grey weathering, pink and grey, nonporphyritic and weakly foliated, and is made up of white to grey feldspar, 20 to 40 percent combined amphibole and biotite (as 5 to 10 mm clots of fine grains or as large ragged plates), quartz, minor pink feldspar and traces of pyrrhotite and pyrite. Unit 4b is a darker and more mafic phase of unit 4a. Xenoliths are moderately common and consist of dark green amphibolite (subunit 15a) and narrow (2 cm) mafic-rich sheets.

Tonalite (subunit 4c) occurs in contact with quartz syenite south of Campbell Lake (where the contact

is marked by irregular 1 to 3 cm pink potassic feldspar veins and coated fractures), as small intrusions and as xenoliths in quartz monzonite and quartz syenomonzonite. The rock is coarse grained, pink weathering, grey on fresh surfaces and contains feldspar, quartz and 35 percent amphibole as large clots of 1 to 2 mm grains. Large amphibole-rich zones possibly represent an assimilated earlier, more mafic phase.

Late-Stage Intrusive Syenogranitic Rocks (Unit 1):

Aplitic syenite (unit 1a) occurs as sills, dykes and veins, and small apophyses at the margins of the Lyle Lake Pluton and elsewhere along the southeastern margin of the Campbell River Group. It crosscuts and is therefore later than the quartz syenite (subunit 1b) and coarse-grained granite (subunit 1d) of the Lyle Lake Pluton. It is a very fine grained (less than 0.5 mm), nonporphyritic, deep pink aplitic rock lacking visible quartz, and weathers to a distinctive brick red colour.

Quartz syenite (subunit 1b) forms the outer zone of the Lyle Lake Pluton and occurs elsewhere as small round intrusions (some within the Campbell River Group), as narrow linear bodies outside the southeastern contact with the Campbell River Group or as sills cutting coarse-grained granite and tonalite.

The rock is fine to medium grained, nonporphyritic, pink weathering, pink to greyish pink on fresh surfaces, lacks visible quartz and consists of greater than 70 percent pink feldspar, less than 5 percent biotite plus amphibole, and traces of pyrite and pyrrhotite. On the west shore of Pear Lake, up to 2 percent fluorite is present as 2 by 10 mm recessively-weathering ellipsoids.

Mafic xenoliths (amphibolite (subunit 15a), amphibolitic calc-silicate (subunit 15c) and meta-argillite (subunit 10b)), ranging in size from 4 cm thick sheets to rafts over 6 m wide, are moderately common. Some of the mafic amphibolite xenoliths contain up to 2 percent pyrite and exhibit reaction rims containing diopside and free carbonate.

Foliation is absent except near the outer edge of the Lyle Lake Pluton where it is locally strongly developed. Along the southeastern shore of Lyle Lake, where quartz syenite is in contact with coarse-grained granite, foliated quartz syenite is cut by chlorite-rich ductile shears paralleled by 2 to 10 cm pegmatite veins.

Some outcrops of this rock type were interpreted as partially assimilated and mobilized meta-arkose (Pyke and Lintott, 1971).

Aplitic veins of quartz syenite, 4 to 15 cm wide, commonly crosscut the quartz syenomonzonite (unit 3) and are in turn cut and offset in places by quartz-feldspar veins.

Fine-grained granite (subunit 1c) occurs as the central core of the Lyle Lake Pluton and elsewhere as small subcircular intrusions, as sills up to 4 m thick cutting quartz monzonite, and in contact with quartzites (subunit 9a) southwest of Campbell Lake. The rock is fine grained, pink weathering, pink to greyish pink nonporphyritic, unfoliated, lacks visible quartz and contains greater than 70 percent pink feldspar and 5 percent biotite.

Xenoliths are rare or absent, exceptions being where narrow screens of fine-grained granite are present along the northwest contact of the Lyle Lake Pluton. Here, thin selvages of mafic material, probably of amphibolitic calc-silicate (subunit 15c), are present as in the neighbouring quartz syenite.

In the extreme southwest, fine-grained granite is in contact with basal quartzites of the Campbell River Group. The contact is generally planar, but in detail at one location the granite is domed into rounded oval 30 cm lobes (possibly representing a spheroidally weathered surface), between which are narrow channels (crack fillings?) of quartzite.

Coarse-grained granite (subunit 1d) occurs as marginal apophyses to the Lyle Lake Pluton and as a separate subcircular intrusion east of Lyle Lake, and forms much of the ground outside the southeastern contact of the Campbell River Group. It is a rusty-weathering, red to salmon-pink to mottled grey and pink, coarse-grained, gneissic to unfoliated rock containing little or no visible quartz, pink and grey feldspar, biotite (in some phases as plates up to 15 mm across), chlorite and traces of pyrite. Xenoliths of meta-argillite and pelite occur rarely.

The unit is crosscut by veins and dykes of quartz syenite 10 to 30 cm thick. The veins are aplitic, straight-sided to wavy with sharp, sometimes coarser grained margins, and contain tourmaline-bearing quartz pods. They are occasionally cut and offset (up to 150 cm) by planar vertical joints and submylonitic zones.

Shear zones (2 to 5 cm and up to 1 m across) are moderately common, especially south of the Campbell River Group where they are oriented between 005° and 045°, and north of the northern contact of the Lyle Lake Pluton where they are parallel to the contact. The fabric in these zones is submylonitic; feldspars within them are round and enveloped by curved interlacing folia of biotite and chlorite.

Porphyritic alkali-feldspar syenite (subunit 1e) forms a distinctive unit at the contact of the Campbell River Group east of Murray Lake, and is

not part of the Lyle Lake Pluton. It is a coarse-grained, deep pink weathering, pink porphyritic rock lacking visible quartz and containing 50 percent potassic feldspar phenocrysts and 10 percent combined biotite and amphibole set in a fine-grained plagioclase groundmass.

Rocks of Uncertain Affinity (Units 6, 7 and 17):

Mafic dyke rocks (unit 6) occur on a small peninsula at the southwest corner of Lyle Lake where the Meshke Creek exits, as a 1.5 m wide mafic body exposed over a strike length of 14 m. The body is discontinuous along strike, dying out at its eastern end to a 2 cm veinlet and an isolated round mass 30 cm in diameter. It has 10 cm wide aphanitic to fine-grained margins and a coarser internal zone in which subround 2 to 50 mm felsic fragments and 2 to 8 mm amphibole crystals are set in a finer groundmass. The fine-grained margins are in sharp contact with both the quartz syenite and the coarser internal zone. Shears in the enclosing quartz syenite are parallel to the margins of the mafic mass. There is no significant compositional variation between the margin and the internal part of the body.

White syenite (subunit 7a) and white syenitic pegmatite (subunit 7b) occur as isolated outcrops between the south shore of a small lake 400 m due north of the northern shore of Lyle Lake and an esker which runs east from Lyle Lake. On the southeastern shore of the small lake, the white syenite is well exposed and contains narrow bands of white syenitic pegmatite (subunit 7b).

The white syenite (subunit 7a) is a coarse-grained felsic rock consisting almost entirely of white feldspar, with mafic clumps of a dark glassy mineral with conchoidal fracture, biotite and magnetite.

The pegmatitic phase (subunit 7b) forms 10 to 15 cm thick bands composed of euhedral, thin, tabular white feldspar crystals with Carlsbad twinning and an interstitial grey mineral (nepheline or sodalite), and scattered 10 mm magnetite and 5 mm monazite crystals.

Contacts with other rock types are not exposed, and its relationships with other rocks of the Peter Lake Domain and with the Lyle Lake Pluton to the south remain uncertain. Nothing resembling these units was found anywhere to the southwest.

Foliated granitoid (unit 17) occurs only along the southeastern contact with the Campbell River Group, in the extreme northeast of the area where the metasediments pinch out. The rock, which appears unusually mafic, is very coarse grained, dark green to black and made up of interlacing chlorite folia (30 percent) wrapped around discoidal 'eyes' of pink feldspar (70 percent). The unit is interpreted as possible sheared and metamorphically retrogressed felsic plutonic rock.

Campbell River Group (Units 9, 10, 11, 12 and 15)

Metasediments:

Representative modal compositions of rocks from the Campbell River Group metasediments are listed in Table 3.

Table 3 - Modal Compositions of Campbell River Group Rocks

UNIT NUMBER	9a	9b	9bN	10a	10b	10c	11	11CG	11L	11N	12a	12b	15a	15b	15b	15c	14	18
MINERAL %																		
K-SPAR	0-15	<1-10	2		7	2										0-1		45
PLAGIOCLASE		1-20				2			5		20-40	0-10	0-30	15		5-59		5
QUARTZ	80-95	60-85	25	33	43	45	26-28	20	20		10-30	50-69	15-28	20	60	0-20		40
BIOTITE	tr-5	7-10		10	10	50	0-3	45	7	35	25-55	30-35	2-30	30	30	0-30		15
PHOGOPITE																	35	
CHLORITE		0-<1	<1					10		8			0-6					
MUSCOVITE	0-7	0-<1		12	40	<1	11-30	15	40	7	0-10							1
AMPHIBOLE											0-15	0-<1	40	10		10-50		
ANTHOPHYLLITE														20h	5	0-15		
ACTINO/TREMO			30														65	
GARNET			25			1												
CARBONATE											0-3	0-15	0-7			0-5		
SPHENE													tr			0-3		
ZIRCON		tr														<1	<1	
EPIDOTE											0-tr		0-<1			0-10		tr
CLINOZOISITE			2															
APATITE	tr										0-1	0-1	tr			0-2	tr	tr
OPAQUE	0-<1	tr		15			2-10	10	20	50	0-5	0-2		5	<1	0-2		
CARBON/CLAY				40			40-50		5									
TOURMALINE	tr	tr																
GROUNDMASS													10-15					

9bN = calc-silicate nodule; 11CG = coarse-grained band; 11L = light-coloured band; 11N = sulphide nodule; h = var. holmquistite

Quartzite (subunit 9a) outcrops along the northwest and southeast contacts of the Campbell River Group and elsewhere is interbanded with pelites.

On the northwest shore of Campbell Lake, the quartzites are in contact with quartz syenomonzonite. The contact dips at 35° to the southeast and is marked by a 10 cm zone of calc-silicate containing 5 to 8 mm red aggregates of pin-head garnets and quartz.

At the southwest end of Campbell Lake, a 50 to 100 cm layer of actinolite calc-silicate separates locally gritty fine-grained quartzite from the fine-grained granite (subunit 1c). The contact is shallow dipping (25° to the east-southeast) and crenulated along axes that plunge gently northeast. Just 100 m to the south is the lobed granite surface invaded by channels of quartzite referred to previously.

On the south shore of the Campbell River (600 m from the southwest end of Campbell Lake), quartzites show cross-bedding and scour-and-fill channels, both of which indicate the succession is locally the right way up. Here the banded calc-silicate quartzite (subunit 9b) lies stratigraphically above the cross-bedded unit.

Subunit 9a comprises moderately fine grained, feldspathic, muscovite-biotite quartzites which are light grey weathering, dark grey to white, finely banded and granular, with sporadic 1 to 2 cm pelitic bands and occasional 1 to 15 cm bands of subangular to subrounded 2 to 10 mm matrix-supported quartz clasts. The banding is parallel to a weakly developed foliation, and where sufficient sericite is present the rock is flaggy. Some outcrops south of Threadneedle Lake are very fine grained to 'cherty'. Outcrops are massive and show little indication of the original bedding except where there are pelitic layers.

Banded calc-silicate quartzite (subunit 9b) has the same distribution as the quartzite, with which it is intimately associated, either as a facies variation or as interbedded material.

The unit is distinguished from quartzite (subunit 9a) by abundant layers and nodules of calc-silicate. It is banded (1 cm wide feldspathic bands and 1 to 2 mm chlorite/biotite-rich layers), grey weathering and dark to light grey. South of Threadneedle Lake, the calc-silicate is in the form of 1 to 15 mm repeated planar bands at regular 5 to 8 mm intervals, giving the rock a striped appearance. Southwest of Campbell Lake, south of the Campbell River, the calc-silicate bands are disrupted, while at the southwest end of Campbell Lake, the calc-silicate is in the form of 5 to 15 cm zoned oval nodules. These have a rim of coarse pink garnet from which laths of white feldspar and green actinolite in a quartz-carbonate matrix radiate towards a core of medium-grained (1 to 5 mm) hornblende-feldspar rock. Sporadic quartz clasts and 1 cm pelitic layers are moderately common.

Boulders of calc-silicate quartzite breccia occur on the northwest shore of Campbell Lake near the quartzite contact. They comprise angular, fine-grained, pink quartzite clasts surrounded by coarse actinolite, hornblende and epidote. The breccia may represent a former carbonate-cemented fault talus.

Slatey argillite (subunit 10a) is best exposed in the area southwest of the Campbell River and occurs elsewhere in more restricted areas. It is a grey- to rusty-weathering, black, finely banded, noncalcareous aphanitic rock with a well-developed slatey cleavage (S_1) that is mainly parallel to the original sedimentary bedding. Surfaces broken across the cleavage show a conchoidal fracture. Cleavage surfaces are frequently limonite coated due to the weathering out of the disseminated and cleavage-bound sulphides (pyrite, pyrrhotite and scarce chalcopyrite); staining varies from light to intense brown to greenish yellow.

The slatey argillite is commonly interbanded with sulphidic mudstone on both a large and small scale. Nodules of sulphidic mudstone also occur embedded in slatey argillite. Lewry et al. (1980) describe such features as concretions; however, an alternative explanation is that they represent the boudinaged remnants of thin interleaved beds of sulphidic mudstone.

Anastomosing quartz veining is rare and closely associated with intruding lamprophyre sills, from which the veins emanate, usually perpendicular to the contacts.

Meta-argillite (subunit 10b), which occurs in the area south and east of Murray Lake, differs from the slatey argillite (subunit 10a) in its lower content of disseminated and cleavage-bound sulphide and lack of rusty-weathering surfaces. It is slightly coarser grained than the slatey argillite, and contains visible crystals of feldspar, and bands or ellipsoids of coarse biotite up to 2 mm thick. Cleavage surfaces are coated with pale green mica or chlorite.

Chloritic phyllite (subunit 10c), which is distributed along the southeastern edge of the Campbell River Group east and northeast of Hornfels Lake, is coarser grained than both the slatey argillite and the meta-argillite, and contains clearly visible chlorite, biotite and feldspar. Cleavage is well developed.

Sulphidic mudstone (unit 11) outcrops primarily in the area east of the north end of Campbell Lake, where it is exposed in beds up to 5 m thick. The

contact of the sulphidic mudstone with the slatey argillite is marked by a prominent continuous EM conductor (Pyke and Lintott, 1971)

The rock is finely banded, dense, carbonaceous, dark grey to black, massive and aphanitic. Although banded, it lacks cleavage and fractures conchoidally. Banding is typified both as a slight colour variation and as continuous layers of very fine grained pyrite and pyrrhotite less than 1 mm thick. Bedding planes, when present, are parallel to the banding and are spaced about 30 cm apart.

Previous authors interpreted this unit as massive fine-grained cherty quartzite (Pyke and Lintott, 1971), or grouped it with the argillites (Lewry et al., 1980).

Pelite (subunit 12a) is widespread over a broad central area within the Campbell River Synform. Xenoliths of identical composition occur in a wide variety of intrusive rocks along the southeast margin of the Campbell River Group. The rock is foliated, fine grained, aphanitic, dark grey to black and consists of chlorite, biotite, quartz, minor amphibole and scattered coarser grains of white (rarely pink) feldspar, together with traces of pyrite. The rock contains sparse siliceous nodules.

Calc-pelite (subunit 12b) has a more restricted distribution than the pelite, being found in close association with that unit only along the southeastern contact of the Campbell River Group between Threadneedle and Campbell Lakes. It is fine grained, dark grey to black, foliated and slightly calcareous or dolomitic. It is frequently cut by hairline calcite veins.

Amphibolite (subunit 15a) occurs along the southwestern margin of the Campbell River Group and at the northeast closure of the Campbell River Synform. The rock is massive, grey weathering, dark grey on fresh surfaces, weakly foliated and consists of 30 percent green hornblende, grey-green feldspar, 10 percent chlorite and traces of chalcopyrite and pyrite, set in an aphanitic groundmass (10 to 15 percent).

Outcrops near the contact of the Campbell River Group south of the Campbell River occasionally contain elongated fish-shaped (10 by 30 cm) hornblende-actinolite inclusions with ophitic texture associated with zones containing 5 to 20 mm angular felsic fragments (subunit 15d, amphibolitic epiclastic) and xenoliths of pelite. Southeast of Threadneedle Lake a parallel-sided 6 m wide body of amphibolite separating quartz syenite from coarse-grained granite is interpreted as a dyke. Southeast of Murray Lake, a 4 m wide sill of quartz syenomonzonite separates the amphibolite from meta-argillite.

Anthophyllite amphibolite (subunit 15b) is found only at one locality 2 km northeast of Hornfels Lake. It is a distinctive medium-grained, dark greenish-black, massive rock composed of amphiboles (anthophyllite and hornblende), dark feldspar and chlorite. A lighter coloured phase is highly quartzitic, comprising predominant quartz and biotite, minor anthophyllite and opaque minerals, and closely resembles quartzitic pelites (subunit 12a) in composition.

Amphibolitic calc-silicate (subunit 15c) is widely distributed, occurring as large masses near Hornfels Lake and as narrow bands near the contact of the Campbell River Group in the southeast. The rock is dark green, massive, weakly foliated to unfoliated and equigranular. Outcrops weather with a pitted surface, featuring large extant stumpy euhedral hornblende crystals. Major component minerals are hornblende, bronzy biotite, pink feldspar and calcite. Traces of pyrite and chalcopyrite, and possibly epidote and diopside, are also present.

Sporadic rounded nodules of resistant-weathering quartzite 4 to 8 cm in diameter, flanked by recessively weathering calcite-rich 'pressure shadows', occur locally. The origin of the nodules is enigmatic. The rock is commonly cut by hairline to 2 cm planar to irregular calcite veins which have pyrite on their contacts, and by hairline quartz veins, on either side of which are zones enriched in pink feldspar.

Amphibolitic epiclastic (subunit 15d) is restricted to two occurrences, one north of Threadneedle Lake where it underlies amphibolitic calc-silicate, and the other between Murray and Campbell Lakes where it is closely associated with amphibolite. The rock is massive, dark greyish green, medium to coarse grained, and contains sporadic 5 to 20 mm diameter angular to subrounded and rounded clasts of medium- to coarse-grained felsic rock set in a granular to ophitic-textured groundmass. The groundmass is composed primarily of hornblende (60 percent), white feldspar (30 percent) and quartz (10 percent); the composite felsic fragments consist of predominant feldspar (85 percent), quartz (14 percent) and minor biotite (1 percent). Smaller fragments are represented by single feldspar crystals.

Intrusives in the Campbell River Group:

Feldspar-mica lamprophyre (subunit 5a) occurs most commonly in the area enclosed by the bend of the Campbell River between Campbell and Murray Lakes, in the form of sills or dykes ranging in width from 30 cm to 3 m or more, most frequently intruding argillite where the contacts are concordant to subconcordant with foliation. The sills frequently branch and tail out and larger bodies

Table 4 - Modal Compositions of Intrusives in the Campbell River Group

UNIT NUMBER	5a	5b	5c	13
MINERAL %				
K-SPAR	35	5-15	3	
PLAGIOCLASE	55	18-50		40-55
QUARTZ	5	0-28	20	25-30
BIOTITE	10	0-25		10-35
CHLORITE		0-7	10	
MUSCOVITE		0-25	20	
AMPHIBOLE		0-25	30	0-5
CARBONATE	tr	tr		tr
SPHENE		tr		
ZIRCON		tr		
EPIDOTE		<1-3		
APATITE				tr
OPAQUE	3	3-7	15	
DEVITRIFIED GLASS		0-25		

are often paralleled by 30 to 60 cm companions of finer grain size. Two of the larger sills occur at the southern edge of the Campbell River Group. Some outcrops are highly fractured, altered and weathered.

The rock is medium grained, buff weathering, grey, unfoliated and porphyritic with large (2 to 5 mm), euhedral, white to rusty plagioclase phenocrysts and clots of coarse biotite plates set in a fine-grained greenish-grey groundmass, which commonly contains minor and rarely up to 15 percent pyrite and pyrrhotite.

Mica-amphibole lamprophyre (subunit 5b) sills, intruded into the argillites, are similar in form, dimensions and distribution to the sills of feldspar-mica lamprophyre. The rock is greyish green, porphyritic and contains phenocrysts of brown to black mica and dark amphibole set in a greyish-green aphanitic groundmass.

Fine-grained mica-amphibole lamprophyre (subunit 5c) is an aphanitic, buff-coloured version of subunit 5b containing 15 percent pyrrhotite and traces of chalcopyrite.

Where lamprophyre sills (subunits 5a, 5b and 5c) intrude rocks other than argillites (as in the area between Threadneedle and Inhospitable Lakes) they are flanked by mica amphibolite.

Quartz diorite (unit 13) outcrops in two places, forming prominent hills near the central part of the Campbell River Synform. A mass of amphibolitic calc-silicate with ill-defined contacts in the larger body of quartz diorite is interpreted as a xenolith. Both bodies appear to have the form of a laccolith.

The quartz diorite is a compact, massive, poorly jointed, weakly foliated to unfoliated, grey porphyritic rock, typified by euhedral tabular white feldspar phenocrysts set in a grey groundmass containing biotite.

Rocks of Uncertain Origin or Affinity Within the Campbell River Group:

Carbonate rock (unit 8) is found only in the area enclosed by the bend of the Campbell River east of its exit from Campbell Lake. Lewry et al. (1980, p. 9) mentioned a possibly similar "light grey to buff-pink medium grained massive felsic rock of indeterminate origin" occurring in several large outcrops in the southwestern part of the belt. Outcrop shows that the body is tabular, mainly concordant to the fabric in the argillite with which it is in contact, but in places slightly transgressive, stepping across the S_1 cleavage. Detailed mapping in the assessment files (Lintott and Pyke, 1972, map 3-113-4B-1) shows that the carbonate body gives way, along strike to the west, to a feldspar-mica lamprophyre sill.

The rock is dense, fine grained to aphanitic, cream coloured to grey, saccharoidal and equigranular with buff-coloured to brown-weathered surfaces and numerous internal irregular limonite-coated fractures. Lintott and Pyke (1972) reported that thin sections show the rock to be made up mainly of magnesite and minor sericite. However, the abundance of limonite on weathered surfaces indicates an iron-rich carbonate, either ankerite or siderite, rather than magnesite.

The carbonate is cut by two 15 cm quartz veins perpendicular to its strike. They contain traces of pyrite, are partially smokey and limonite stained, and emit a sour onion-like smell when struck.

The close association with the lamprophyres may mean that the carbonate rock is of igneous origin (i.e., a carbonatite). However, the large quantity of calc-silicate rock elsewhere in the Campbell River Group leaves open the possibility that this is an unmetamorphosed iron- and magnesium-rich sedimentary carbonate.

Mica amphibolite (unit 14) is restricted to the southern margin of the Campbell River Group between Murray and Hornfels Lakes, where it is closely associated with lamprophyre sills, being marginal to them in nearly every occurrence. The rock is coarse grained, dark green, irregularly foliated to schistose and contains bronzy phlogopite, chlorite (both disseminated in the body of the rock and coating foliation planes), amphibole, calcite and possibly talc.

Hornblendite (unit 16) occurs rarely as 60 cm thick sills parallel to the banding of the sulphidic

mudstone, in outcrop and drill core from the Campbell River area. It is a distinctive coarse grained, dark green to black rock consisting of an estimated 80 to 90 percent hornblende as randomly oriented interlocking blades.

Meta-arkose (unit 18) is found in a few places as frost-heaved angular boulders, together with fragments of quartzite, near outcrops of pelite and as narrow coarse-grained pink and dark grey gneissose bands within meta-argillite. The rock is medium to coarse grained, gritty, unsorted, pinkish brown and granular, and contains 20 to 40 percent feldspar, 60 to 80 percent quartz and 1 to 2 percent magnetite.

VEINS, JOINTS AND FRACTURES

Quartz veining is present to some degree in all the felsic plutonic rocks but is uncommon to rare in the supracrustals. The variety of types and range of host rock compositions is shown in Table 5, and their relative abundance in Table 6. Some veins have marginal coatings of hematite, chlorite, potassic feldspar or epidote, and may contain traces of disseminated pyrite, chalcopyrite or tourmaline.

Jointing in the felsic plutonic rocks is generally widely spaced, planar, flat-lying and vertical. Areas of close to very close spacing, and more irregular jointing and fracturing are common only in the aplitic syenite and quartz syenite, whose outcrops often have a characteristic brecciated appearance. Coatings of manganese oxides, magnetite, chlorite, epidote, hematite, or biotite and traces of chalcopyrite are sometimes present on the fracture surfaces.

Table 5 - Type and Distribution of Quartz Veins

TYPE OF VEIN	HOST ROCK
Discoidal, pinch and swell veins 5-50 mm wide 30 cm in diameter	Quartz-syenite Fine-grained granite Quartz-monzonite Quartz-syenomonzonite Quartz-syenodiorite
Quartz knots and pods	Aplitic syenite Quartz syenite Quartz monzonite
Hairline to 2 cm planar veins (cut and displace all other types)	ALL FELSIC PLUTONIC ROCK TYPES
Hairline to 3 cm irregular branching and anastomosing veins (sometimes forming quartz-cemented breccias)	Quartz-syenite Fine-grained granite

RADIOMETRIC CHARACTERISTICS

Background total count radiation in the area is in the range 80 to 200 counts per second. Table 7 lists the anomalously radioactive rock types.

Anomalies associated with the syenitic rocks reflect their high potassium and/or REE, Th and U content; those associated with slatey argillite and sulphidic mudstone probably relate to uranium concentrations associated with the carbon content.

STRUCTURE

The Campbell River Group lies in a regional asymmetrical synform with a flat-lying northeast-trending major axis. Bedding and foliation (S_1) commonly dip southeast on both sides of the synform, indicating that the synform is overturned to the northwest. Related minor fold structures in the area between Campbell and Murray Lakes are visible in outcrop as crenulations and, on a larger scale, are apparent from the disposition of marker horizons, such as the sulphidic mudstone with its characteristic EM signature (see Pyke and Lintott, 1971).

In greater detail, to the northeast of the Campbell River, the strike of bedding planes and foliation in the metasediments is generally northeasterly, with steep (60^0 to 80^0) dips to the northwest and southeast. At the margin of the larger quartz diorite laccolith, the strike is deflected parallel to the contact of the intrusion. Along the southeastern margin of the synform, in the areas northeast of Inhospitable Lake and east of Murray Lake, folds are tight to isoclinal. The preponderance of southeasterly dips here indicates that the fold structures are mostly overturned to the northwest. Here also the contact between the Campbell River Group and the felsic plutonic rocks is discordant and possibly faulted; it is inferred that the Campbell River rocks are overthrust by the felsic plutonic rocks. Argillites from these areas show a well-developed second cleavage (S_2) at high angles to the S_1 cleavage.

Table 6 - Abundance of Quartz Veining

RARE	Quartz-monzodiorite & tonalite
SCARCE	Aplitic syenite & quartz-monzonite
UNCOMMON	Quartz-syenomonzonite
MODERATELY COMMON	Fine-grained granite

Table 7 - Anomalously Radioactive Rock Types

UNIT	TOTAL COUNT RADIOMETRICS
Aplitic syenite	170-400 cps
Quartz-syenite	300-450 cps
Porphyritic Alkali-feldspar Syenite	300 cps
White Syenite	400-600 cps
White Syenitic Pegmatite	800-850 cps
Slatey Argillite	200-420 cps
Sulphidic Mudstone	250-300 cps
Carbonate Rock	300-320 cps

Southwest of the Campbell River, folding is more open, strikes are locally extremely variable and dips are shallower (12° to 70°) than in the remainder of the metasedimentary belt to the northeast.

The foliation, long axes of xenoliths and most of the shear zones in the plutonic rocks southeast of the Campbell River Group parallel regional (F_2) fold axes. West of the Campbell River Fault and northwest of the synform, foliation and shears are generally lacking.

The Rutherford and Campbell River faults are major north-trending tear faults with sinistral displacements of up to 200 m which cut across the felsic plutonic rocks, the Campbell River Group, the lamprophyre sills and the larger quartz diorite laccolith. These and numerous parallel but less continuous sinistral faults which occur at regular intervals along the length of the synform belong to the D_5 phase of brittle deformation of Lewry et al. (1980). The Campbell River Fault appears to be a major break separating two areas with differing degrees of structural deformation.

METAMORPHISM

The metamorphic grade within the Campbell River Group is generally low. Lewry et al. (1980) define it as uppermost greenschist to lower amphibolite facies, occurrences of lower greenschist or subgreenschist facies being attributed to retrogression along shears and faults. West of the Campbell River Fault, the argillites and mudstones show little sign of recrystallization, retaining their fine grain size, carbonaceous material and possibly some clay mineral content. East of the fault, along the southeast contact, argillites and quartzitic and feldspathic pelites are noticeably recrystallized but still low grade, with the development of chlorite and mica in the groundmass and along the phyllitic S_2 cleavages.

ECONOMIC GEOLOGY

The main characteristics of the sulphide mineralization in the Campbell River Group have been described by Pyke and Lintott (1971), who noted that the black carbonaceous argillites contain up to 10 percent pyrite, 10 percent fine, evenly disseminated pyrrhotite and 4 percent sphalerite as small blebs associated with spherical or oval 1 to 30 mm pyrite nodules. Lesser amounts of pyrite (up to 3 percent) are recorded in interbedded massive grey quartzites. The mineralization is attributed to syngenetic deposition of the sulphides in black muds in a euxinic environment.

Concentrations of sphalerite mineralization occur along the silicified contacts of lamprophyre sills (which themselves contain up to 10 percent pyrite and pyrrhotite) intruding the argillites. Analyses of drill core show that the argillites contain up to 0.13 percent Pb and 0.23 percent Zn over 3 feet and up to 0.37 percent Zn over 5 feet (Lintott and Pyke, 1972). Lewry et al. (1980) described the sulphides as concentrated in laminae parallel to the bedding in the argillite; minor chalcopyrite is recorded in calcareous hornblende-biotite gneisses.

The current work confirms the style and type of mineralization; examination of the sulphidic mudstone shows that the sulphide laminae are regular and parallel to fine-scale variations in lithology which are taken to represent original bedding. Fractures in the sulphidic mudstone and the S_1 foliation surfaces also contain pyrite, demonstrating that later phases of sulphide mineralization or perhaps redistribution of the stratabound sulphides has occurred.

In the Zechstein copper deposits (Kupfershiefer) of Poland, Kucha (1982) noted that gold (up to 3000 ppm), platinum (10 to 370 ppm) and palladium (10 to 120 ppm, rarely up to 1000 ppm) occur together with a wide range of transition metals in a mineralized horizon a few centimetres thick at the oxic/anoxic facies boundary, where black shales are overlain by phosphatic borate- and thucolite-bearing shales.

Accordingly, samples of slatey argillite and sulphidic mudstone are being analyzed for Au, Pt and Pd, as well as Ba, Th, Ga, In, Cu, Zn, Ag, Hg, Cd, Sn, Pb, Ni, Co, U and V. Analytical work is also being undertaken on the undersaturated syenites to evaluate their potential for REE, U, Y, Ga, Li, Be, Nb and Ta.

DISCUSSION

The Sedimentary Succession

The cross-bedding and scour-and-fill channels observed in the quartzites near their contact with felsic plutonic rocks suggest that the succession is locally the right way up and that the quartzites are near the base of the exposed succession. Pyke and Lintott (1971) estimated the total thickness at between 120 and 180 m, although estimates are difficult due to discontinuity of exposure, uncertainty as to the extent of repetition caused by folding and thinning out caused by either

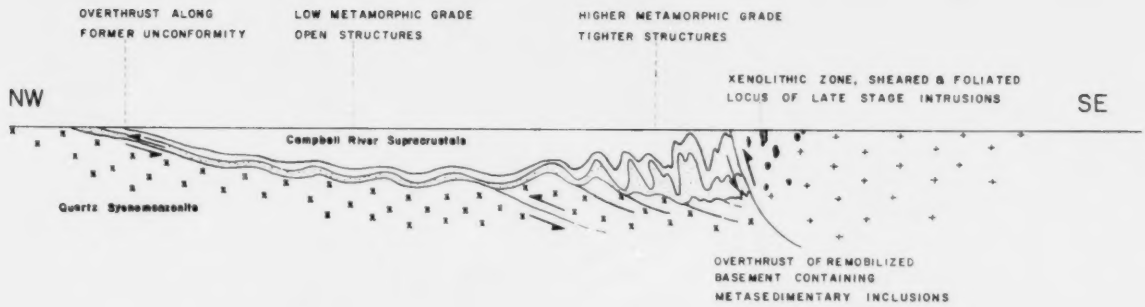
OVERTHRUST ALONG FORMER UNCONFORMITY
LOW METAMORPHIC GRADE OPEN STRUCTURES
HIGHER METAMORPHIC GRADE TIGHTER STRUCTURES
XENOLITHIC ZONE, SHEARED & FOLIATED LOCUS OF LATE STAGE INTRUSIONS
NW
SE
Campbell River Supracrustals
Quartz Syenomonzonite
OVERTHRUST OF REMOBILIZED BASEMENT CONTAINING METASEDIMENTARY INCLUSIONS

Figure 1 - Sketch section across Campbell River Synform showing possible structural relationships.

compression or internal thrusting, and doubts about the degree of facies equivalence of certain units. The total thickness of the Campbell River Group is suggested to be 530 to 630 m.

The amphibolitic rocks (unit 15) may be in part metamorphosed equivalents of former carbonate-rich sediments such as iron dolomites and siderites, while others are possibly former volcaniclastic rocks, as suggested by Lewry et al. (1980). The absence of amphibolitic units from most of the northwestern side of the synform and the close association of the quartzites with amphibolitic calc-silicate, and of the pelites with amphibolite and anthophyllite amphibolite on the southeastern and northeastern sides of the synform may indicate that the amphibolitic rocks are facies equivalents of the quartzitic and pelitic sediments.

Relationship of the Campbell River Group to the Surrounding Terrane

The northeastern contact of the Campbell River Group is ambiguous and accommodates neither an intrusive nor an unconformable relationship. There is no conglomeratic layer at the contact and, although gritty bands occur within 1 or 2 m of the base of the quartzite unit, they contain no fragments of plutonic igneous rock. There are neither xenoliths of quartzite in the adjacent quartz syenomonzonite and granite, nor veining of the quartzite by pegmatitic or aplitic phases of the plutonic rocks. The actinolitic and other calc-silicate layers at the contact might be interpreted as a feature of contact metamorphism but for the fact that such calc-silicates also occur as bands and nodules in the banded calc-silicate quartzite higher in the succession, where they are evidently the product of regional rather than contact metamorphism. It is possible that the quartzite/plutonic rock contact around Campbell Lake is a low-angle thrust developed at the site of a former unconformity at the base of the quartzite unit, the calc-silicate zone perhaps representing the metamorphosed version of an imbricate sole.

However, along the southeastern margin, evidence of an intrusive relationship is suggested by the occurrence of xenoliths in the felsic plutonic rocks: the same contact is discordant and marked by tight fold structures in the Campbell River Group. It is tentatively interpreted as a steep overthrust of partially remobilized and intrusive former basement derived from a deeper structural and metamorphic level (see Fig. 1).

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Project 8724

Bedrock Geology, Iskwatikan Lake Area: Evidence for Hudsonian Juxtaposition of Proterozoic and Archean Rocks along a Ductile Detachment Surface

by J.R. Chiarenzelli[1], J.F. Lewry[2] and M. Landon[3]

Chiarenzelli, J.R., Lewry, J.F. and Landon, M. (1987): Bedrock geology, Iskwatikan Lake area: evidence for Hudsonian juxtaposition of Proterozoic and Archean rocks along a ductile detachment surface; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

Geological mapping of bedrock exposures in the Iskwatikan Lake area was begun in July 1987. Approximately 100 km^2 were mapped at 1:20,000 in conjunction with J.R. Chiarenzelli's dissertation work on the Nistowiak Gneisses (Lewry, 1984; Lewry and Slimmon, 1985; Chiarenzelli and Chiarenzelli, 1986). Iskwatikan Lake is approximately 65 km by air from La Ronge, and can also be reached by the Rapid River Portage from Lac La Ronge and the Nistowiak Falls Portage from the Churchill River System. Reconnaissance work and sample collection were carried out in the area of Thomas Lake, and Campbell, Hunter, Pothole and Russell Bays, Lac La Ronge (Fig. 1). Additional work carried out this season north of Nistowiak Lake and in the Drinking Lake area will be reported at a later date.

Previous geological mapping in the region is described by Mawdsley and Grout (1951) and Morris(1962). Reconnaissance geological investigation of the region was carried out by J.F. Lewry (1984) and the area is included in a geological compilation map by Lewry and Slimmon (1985). The contiguous Nistowiak Lake area to the north was mapped by Chiarenzilli and Chiarenzilli (1986).

Preliminary geochronological results obtained this spring indicated the presence of Archean rocks in what was known as the Iskwatikan Lake Pluton (Lewry and Slimmon, 1985). Highly strained plutonic rocks similar to those mapped in the Nistowiak Lake area last year (Chiarenzelli and Chiarenzelli, 1986) are also known to crop out in the area. It was accordingly decided to map out the possible extent and regional context of the Iskwatikan Lake Pluton as well as the southern extension of the high strain zones, as a means to arriving at a better understanding of the tectonics and structural problems of the area (Lewry, 1984).

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Background Geology

The Iskwatikan Lake area lies in the Glennie Domain of the Proterozoic Trans-Hudson Orogenic Belt (Lewry, 1981). Lewry (1984) has subdivided the Glennie Domain into two parts based on structural positioning and lithological differences. The northern part, known as the Wapassini Allochthon, consists predominantly of mixed supracrustal rocks similar to those of the adjacent MacLean Lake Belt of the La Ronge Domain. To the south, and structurally underlying the Wapassini Allochthon, is the Iskwatikan Subdomain, which consists predominantly of variably strained plutonic rocks. The boundary between these distinct terrains is marked by the Guncoat Thrust, a sole zone of highly strained and migmatized pelitic and psammitic gneisses known as the Guncoat Gneisses.

Lewry (1981) originally proposed on field evidence that the Glennie Domain was an Archean microcontinent which collided with the Proterozoic La Ronge arc to produce telescoping of the intervening fore-arc basin and thrusting of the Wapassini Allochthon over the Iskwatikan Subdomain. When subsequent geochronological work failed to substantiate the presence of Archean rocks in the Glennie Domain, a reinterpretation was presented (Van Schmus et al., 1987; Lewry et al., 1987).

Preliminary structural and isotopic data associated with this study now suggest that the Iskwatikan Lake area forms the lowest exposed structural level of the Glennie Domain and is underlain extensively by Archean rocks which are separated from overlying Proterozoic rocks by intervening zones of high strain.

Lithologic Units

The shoreline of Iskwatikan Lake coincides approximately with the northeastern boundary of the Iskwatikan Lake Pluton of Lewry and Slimmon (1985). This summer's work shows the pluton to comprise a number of rock types, and structural

Figure 1 - Location and generalized structural trend map of the Nistowiak - Iskwatikan - Hunter Bay areas. Major waterways are outlined in stipple. Rectangular area corresponds to the 1:20,000 scale map accompanying this report. Open teeth, moderate dips; closed teeth, steep dips; back-to-back teeth, vertical dip. Topographic base and structural data from Lewry and Slimmon (1985). Numbers correspond to localities mentioned in text: 1, Nistowiak Lake; 2, Drinking Lake; 3, Iskwatikan Lake; 4, Hale Lake; 5, Russell Bay; 6, Kenderdine Island; 7, Thomas Lake; 8, Campbell Bay; 9, Pothole Bay; 10, Hunter Bay.

data indicate that the feature is actually an elongate northeast-trending doubly-plunging anticline cored by Archean rocks (Fig. 1). In view of this new information, the feature is renamed the Iskwatikan Lake Complex. The complex essentially comprises tonalitic and granitic gneisses which are described below as units 1 and 2.

Unit 1 - Tonalitic Gneiss

Coarse-grained biotite-bearing tonalitic gneisses which crop out around the shores of Iskwatikan Lake form the oldest coherent rock unit yet recognized in the area. Magnetite is a common accessory mineral. The gneisses are variably strained and generally show a coarse megacrystic texture accentuated by resistant elongate quartz domains. Amphibolitic xenoliths occur locally. Local migmatite contains 5 to 10 percent leucotonalitic leucosome which both crosscuts or is concordant to foliation.

The quartz dioritic to mafic tonalitic gneisses occupying the centre of Nistowiak Lake about 3 km north of Abram Island and previously termed the Nistowiak Lake Complex (Chiarenzelli and Chiarenzelli, 1986) are now included tentatively in unit 1.

Unit 2 - Granitic Gneiss

2A - Megacrystic to Flasered Granitic Gneiss: Unit 2A occurs in a concentric sheet which is in contact with and contains zenoliths of tonalitic gneisses of the enveloping unit 1. The rock is variably strained, varying from intensely flasered protomylonite to well-developed augen gneiss. The augen are composed or pink potassium feldspar up to several centimetres in size. Similarly to the tonalitic gneisses, the rock is rich in biotite and magnetite. At least one outcrop of a rapakivi-textured granitic gneiss was noted. Granite gneisses exposed in Campbell Bay, Lac La Ronge contain several percent garnet.

2B - Migmatitic Granitic Gneiss: The central part of Iskwatikan Lake is underlain by highly migmatitic granitic gneisses and deformed to

undeformed pink potassium feldspar pegmatites, granites and aplites of a probable wide range of ages. These rocks appear to be derived from unit 2A, commonly containing nebulous domains of megacrystic or flasered granitic gneiss and xenoliths of tonalitic gneiss. Structural trends are weakly defined and partially obliterated in the migmatitic core of the Iskwatikan Lake Complex. The considerable range in deformation is attributed to continued partial melting of the Archean host at different times during Hudsonian deformation.

The rocks examined in the Iskwatikan Lake region strongly resemble rocks exposed on islands in the centre of Hunter Bay, Lac La Ronge (Fig. 1), although there the tonalitic gneisses appear to be relatively more abundant. The possible temporal correlation of these rocks will be tested by U-Pb zircon geochronology.

Unit 3 - Supracrustal Rocks

Supracrustal rocks occur around the margins of the Iskwatikan Lake Complex. They are similar to rocks described by Chiarenzelli and Chiarenzilli (1986) in the Nistowiak Lake area and are thought to be part of the same supracrustal sequence. As the supracrustals have not been found in contact with the Iskwatikan Lake Complex, their age relationship is not known. Instrusive relationships do show, however, that the supracrustals are older than the plutonic suite discussed in the section below (unit 4).

There is a general sequence of supracrustal units in the area and in the area to the north consisting, from the base, of hornblende gneisses, psammites, pelites, and marble. The significance of this apparent stratigraphy remains to be demonstrated.

It is interesting to note that marble has not been found in the map area but has been observed nearby to the southeast in Hale Lake where, along with exposures at Kenderdine Island, Lac La Ronge (Fig. 1) it occurs as large tectonic blocks in high strain zones.

3A - Hornblende Gneisses and Amphibolite: Hornblende gneiss and amphibolite are the most common supracrustal rocks in the Iskwatikan Lake area, forming discontinuous layers and elongate bodies in shear zones and granodiorite gneisses. The hornblende gneisses are medium- to fine-grained mafic rocks composed of hornblende, plagioclase and local diopside with centimetre-scale mineralogical layering that is continuous at outcrop scale. Interlayers of boudinaged hornblendite up to 1 m thick are common. Similar rocks are known from the Nistowiak Lake area (Chiarenzelli and Chiarenzelli, 1986) and above the Guncoat Thrust (Morris, 1962) and are thought to represent mafic to intermediate metavolcanics and related metasediments. South of Iskwatikan Lake the hornblende gneisses are interlayered with psammitic gneisses.

Amphibolite composed essentially of hornblende and plagioclase in subequal amounts is also common. Minor accessory minerals include garnet and quartz. The rock is medium- to coarse-grained with a slight preferred mineral orientation or compositional layering defining foliation. Granoblastic textures are common, as are coarse-grained leuco-amphibolitic segregations. Amphibolite layers and xenoliths are an abundant component among gneisses outcropping in shear zones in the area (unit 6). In at least one area plagioclase phenocrysts occur within an amphibolitic unit, suggesting a volcanic origin for at least some of these rocks. The relationship between amphibolite and hornblende gneisses is obscure and they are not necessarily of the same age or origin.

3B - Psammitic Gneisses: Monotonous gneisses containing plagioclase, quartz, biotite and local hornblende, typically with several percent plagioclase megacrysts, are provisionally interpreted as psammitic gneisses. Hornblende occurs in randomly oriented porphyroblasts 2 to 3 mm in size, suggestive of late static metamorphic growth. Similar rocks in the Nistowiak Lake area have yielded zircon populations with morphologies suggestive of a detrital origin. Nonetheless, as can be clearly seen several kilometres north of Stewart Bay, these rocks commonly appear to be gradational into granodioritic plutonic rocks, possibly suggesting derivation of at least some of the granodioritic gneisses from partial melting of the supracrustal rocks.

3C- Pelitic Gneisses: Pelitic gneisses composed of plagioclase, biotite, quartz, garnet and local sillimanite are exposed in a thin layer in the northeast, continuous with similar rocks in the Nistowiak Lake area. Many of these rocks contain up to 20 percent plagioclase megacrysts. Biotite-plagioclase-quartz gneisses are exposed along the eastern shore of Iskwatikan Lake in small discontinuous outcrops which possibly correlate with other pelitic/psammitic gneisses in the area.

Unit 4 - Proterozoic Plutonic Rocks

Unit 4 comprises a variety of granitic to gabbroic gneisses of suspected Proterozoic age which occur around the periphery of the Iskwatikan Lake Complex. These rocks are mainly granodioritic and identical to the plutonic rocks examined in the Nistowiak Lake area last season (Chiarenzelli and Chiarenzelli, 1986). Xenoliths of unit 3 type supracrustal rocks ranging in size from a metre to several kilometres in length are common. A well-exposed transition from biotitic granitic gneiss, through hornblende granodiorite and diorite, to a metagabbroic core was noted east of Rabbit Bay, indicating an origin as a compositionally zoned pluton.

4A - Granodioritic and Quartz Dioritic Gneisses: Hornblendic granodioritic gneisses which locally grade into megacrystic quartz dioritic gneisses are the dominant rock type in unit 4. Most of these rocks are highly strained and only in the far southeast is a relict megacrystic texture preserved. Migmatitic leucosomal segregations composed of coarse-grained plagioclase, quartz and hornblende are common. Granodioritic sheets also form concordant intrusions into unit 4 type supracrustal rocks on all scales. On the other hand, granodioritic gneisses have not been observed in contact with rocks of the Iskwatikan Lake Complex, suggesting their present proximity may be the result of tectonic transport.

4B - Granitic, Syenitic, and Leucogranitic Gneisses: Biotite- and hornblende-bearing granitic, syenitic and leucogranitic gneisses occur in small elongate bodies. In many places these appear to grade into the more mafic granodioritic gneisses. Highly strained pink leucogneisses which occur interlayered with amphibolite approximately 2 km north and east of Bettin Island may, however, be unrelated to the unit 4A granite-gabbro plutonic suite.

Unit 5 - Syn- and Post-Tectonic Aplites, Granites and Pegmatites

Strongly deformed to undeformed pink potassium feldspar-bearing pegmatites, granites and aplites occur in the map area and in the Nistowiak Lake area to the north (Chiarenzelli and Chiarenzilli, 1986). While exhibiting a range of deformational features, they also crosscut all other rocks in the area.

Plagioclase is common in this unit, although subordinate in amount and size. Accessory minerals are generally sparse but include biotite, garnet, muscovite and magnetite. Most bodies have dyke or sill forms. Many of the dykes are zoned, with feldspar margins and quartz-filled interiors. The pegmatites contain quartz and large perthitic potassium feldspar crystals up to 1 m in length. Some areas, particularly in the core and northeastern margin of the Iskwatikan Lake Complex, are almost entirely composed of late pegmatite and granite masses with large rotated xenoliths of host rock. A late brittle northeast-trending cataclastic fabric is locally developed. However, unlike the Drinking Lake area to the north, there is no evidence to suggest emplacement of pegmatite or granitic dykes along brittle fractures (Chiarenzelli and Chiarenzelli, 1986).

Unit 6 - Nistowiak Gneisses

Highly strained mylonitic to migmatitic plutonic rocks with amphibolite blocks and layers and subordinate supracrustals, identical to those termed the Nistowiak Gneisses (Lewry, 1984; Lewry and Slimmon, 1985; Chiarenzelli and Chiarenzelli, 1986), outcrop more or less continuously along the shoreline of Iskwatikan Lake. This outcrop ranges in width from several hundred metres to two or more kilometres, but along the northeastern part of Iskwatikan Lake the unit is poorly exposed, occurring primarily as xenoliths in late granitoids.

The unit forms the boundary separating the Iskwatikan Lake Complex from the enveloping supracrustal and plutonic gneisses of probable Proterozoic age, and is thought to have derived by severe ductile deformation of both Archean and Proterozoic rocks. High amplitude isoclinal and/or sheath folds have deformed lithologic variations and a mylonitic fabric. The mylonitic fabric is granoblastically recrystallized, indicating that deformation took place relatively early in the metamorphic history.

Similar rocks in the northwestern corner of the map area form part of the outcrop mapped last summer in Nistowiak Lake. These gneisses appear to be a similar although spatially distinct zone of high strain.

Structure

Aside from the late granitoids of unit 5, all rocks in the area possess a well-developed preferred planar mineral orientation. In plutonic rocks this foliation is shown by elongate feldspar megacrysts, quartz domains, preferentially orientated hornblendes or biotites. In addition, leucosomal segregations, transposed primary features and compositional layering commonly parallel mineral orientation in both plutonic and supracrustal rocks.

The Iskwatikan Lake Complex forms the core of a doubly-plunging antiform with a northeast-trending axial trace which is believed to be related to the regional D_4 folding (Lewry and Slimmon, 1985) shown in the neighbouring Drinking Lake Synform and Hunter Bay Antiform (Fig. 1). The antiform has steep limbs and moderate northeasterly plunge. These regional northeast-trending D_4 folds refold an earlier flat-lying foliation and early isoclinal folds.

Linear fabrics of several types are common in the area. Mineral lineations generally plunge northwest on the northwest limb of the Iskwatikan Lake Antiform and southeastward on the southeast limb, suggestive of refolding about the axis of the D_4 structures. Quartz-feldspar rodding common in migmatitic rocks generally trends northeast, parallel to the major D_4 structures in the area.

Lineations of other types and mostly northerly orientation may be related to other folding or refolding events.

Fold generations: As least one generation of early isoclinal folds is present in the area. These are postdated by open to tight folds of various orientations, which are particularly dominant in the hinge of the Iskwatikan Antiform where they mimic the orientation of the major fold.

Metamorphism

With the exception of the posttectonic granitoids, the region was generally metamorphosed to upper amphibolite facies grade with attendant migmatization. Feldspar megacrysts up to several centimetres long, which are common in the pelitic, psammitic and granodioritic rocks, are interpreted mainly as disaggregated leucosomal or early pegmatitic injections. Orthopyroxene was noted in a few coarse-grained leucosomal or metamorphic segregations, indicating at least local attainment of granulite facies conditions. There appears to be a general increase in metamorphic grade southwestward from Drinking Lake to Russell Bay approaching the Stanley Shear Zone.

Concluding Remarks

Preliminary U-Pb zircon geochronolgy, revised structural interpretations presented by Lewry et al. (1987) and new field data allow reinterpretation of the geology of the Iskwatikan Lake area. The Iskwatikan Lake Pluton identified by Lewry and Slimmon (1985) is now considered to be an Archean core of a northeast-trending antiformal dome (the Iskwatikan Lake Antiform) related to D_4 folding. Structural and lithologic similarities between this area and Hunter Bay indicate that the Iskwatikan Subdomain (Lewry, 1984) may contain a considerable volume of Archean rocks, perhaps vindicating Lewry's (1981) interpretation on the origin of the Glennie Domain.

The highly strained Nistowiak Gneisses (Unit 6) which envelop the Iskwatikan Lake Complex are interpreted as the boundary between rocks of Archean and Proterozoic age, and may be a regionally important ductile detachment surface. Lithologic and textural similarities between these rocks and those known as the Hunter Bay and Nistowiak Gneisses (Lewry, 1984; Lewry and Slimmon, 1985; Chiarenzelli and Chiarenzelli, 1986) suggest all have a comparable signifiance. Regional structural problems associated with the outcrop trace of these rocks remain to be solved.

This new information provides additional evidence for a Hudsonian collisional event between the Glennie and La Ronge Domains, involving rocks of Archean age, considerable crustal shortening and thickening by thrust stacking (Lewry, 1981).

The close association and intimate relationship of syn- and post-deformational pegmatite with the migmatitic core of the Iskwatikan Lake Complex suggests derivation, at least in part, of the pegmatite by partial melting of an Archean granitoid source. The large quantities of pegmatite noted in this area, as well as in the Nistowiak Lake area to the north (Chiarenzilli and Chiarenzilli, 1986) and in the Glennie Domain in general, may suggest that a significant volume of Archean rocks are buried at depth. Sm-Nd model age and inherited zircon studies of these late granitoids should provide information on this suspected Archean underlay.

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Project 8731

Gold Metallogenic Studies, Sulphide and PAP Lakes Area

by D.C. Armstrong[1] and G.R. Parslow[1]

Armstrong, D.C. and Parslow, G.R. (1987): Gold metallogenic studies, Sulphide and Pap Lakes area; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

During the summer of 1987 a study of the gold mineralization in the Sulphide - PAP Lakes area was undertaken in order to provide a better understanding of the geology of the area and the genesis of the mineralization.

The Sulphide Lake area is located approximately 50 km northeast of the town of La Ronge and occupies the central portion of the Stanley (west half) area (NTS 73P-7W). It hosts numerous gold showings, including the Studer A-F, PAP SW, A and B, Main Camp, Clearwater, Turtle Lake, Ramsland and Preview Lake prospects, which together form a northeast-trending belt with a strike extent of 20 km (Fig. 1).

Previous geological investigations carried out by the Saskatchewan Geological Survey in the Sulphide - PAP Lakes area include work by Forsythe (1968, 1971), Coombe (1976), Sibbald (1984, 1986) and Scott (1984). Coombe (1984) also produced a compilation and review of individual gold occurrences.

During the current geological studies, detailed mapping and sampling of surface outcrops and logging of drill core was undertaken, principally in proximity to the Studer A, B and C and PAP gold occurrences, to establish stratigraphic, lithologic and structural relationships. Geochemical, petrological, fluid inclusion and isotope work will be

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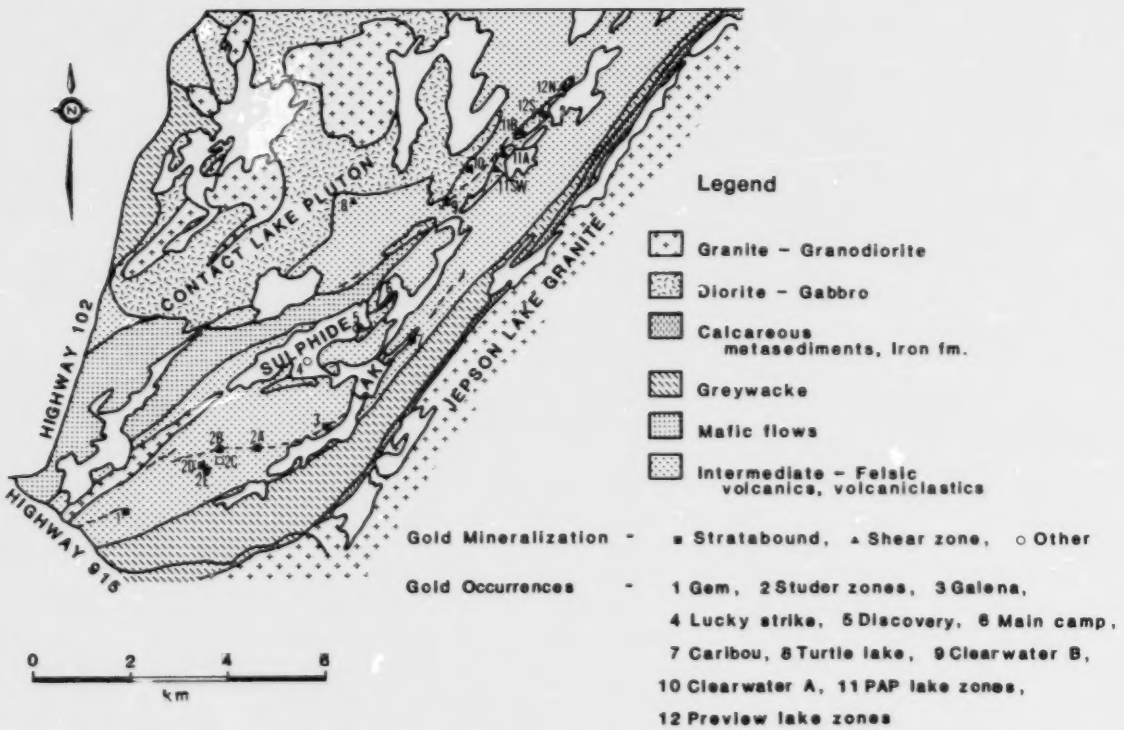
CONTACT LAKE PLUTON
SULPHIDE LAKE
JEPSON LAKE GRANITE
HIGHWAY 102
HIGHWAY 918
Legend
Granite - Granodiorite
Diorite - Gabbro
Calcareous metasediments, iron fm.
Greywacke
Mafic flows
Intermediate - Felsic volcanics, volcaniclastics
Gold Mineralization - ■ Stratabound, ▲ Shear zone, ○ Other
Gold Occurrences - 1 Gem, 2 Studer zones, 3 Galena, 4 Lucky strike, 5 Discovery, 6 Main camp, 7 Caribou, 8 Turtle lake, 9 Clearwater B, 10 Clearwater A, 11 PAP lake zones, 12 Preview lake zones
0 2 4 6
km

Figure 1 - Regional geology, Sulphide - PAP Lakes area (after Sibbald, unpublished manuscript map).

carried out on the sampled material. A brief examination was made of other gold prospects in the study area (e.g., Main Camp, Clearwater, Turtle Lake, Ramsland, Preview Lake) for comparative purposes. A regional lithogeochemical sampling program was also initiated, the main objectives being to characterize the tectonic setting of the metavolcanic and intrusive rocks. It has been suggested that the Nut Bay Belt (which includes the Sulphide - PAP Lakes area) may represent a southern dismembered extension of the Central Metavolcanic Belt (Coombe et al., 1986; Thomas, 1987).

Regional Geology

The area is underlain by a northeast-trending supracrustal sequence of metavolcanic and metasedimentary rocks that have been intruded by numerous bodies of gabbroic to granitic composition, including the large Contact Lake Pluton and sill-like Jepson Lake Granite. The rocks have been metamorphosed to upper greenschist/lower amphibolite facies and the supracrustal sequence has been subjected to at least two episodes of deformation (Sibbald, 1986).

Table 1 - Generalized Stratigraphic Succession (from Southeast to Northwest)[1]

Unit	Description
6	Calcareous metasediments, mixed oxide-silicate-sulphide iron formation
5	Monotonous, well-laminated psammopelitic metasediments (upper greywackes)
4	Felsic to intermediate metavolcaniclastics, minor pillowed flows (meta-andesite?), interlayered pelitic metasediments, in part carbonaceous and sulphidic (lean iron formation)
3	Mafic pillowed flows, intercalated mafic sills (this unit interdigitates with Unit 2 and thins to northeast)
2	Intermediate to felsic flows and metavolcaniclastics, calcareous metasediments, mixed silicate-sulphide iron formation
1	Psammopelitic metasediments, in part calcareous (lower greywackes)

[1]after Sibbald (1986)

The area is dominated by the Contact Lake Pluton, a composite intrusion of gabbroic to granitic composition with an areal extent of 60 km^2. The margins of the pluton appear to consist mainly of the most mafic (gabbroic) phases, while the central portions consist of the more felsic phases, with boundaries being gradational. Using the classification of Harper et al. (1986) for the Star - Waddy Lakes area, the Contact Lake Pluton appears to be a type 1 intrusive. The crude zonation could have resulted from injection of the mafic phases first, followed by injections of successively more felsic material as the underlying reservoir continued fractionating. However, lithogeochemical studies need to be undertaken to confirm this. The close proximity of the Contact Lake Pluton to the gold occurrences in the Sulphide - PAP Lakes area suggests that it may have played an important role in the mineralization process, either as a direct source or as a heat engine for circulating fluids.

Sibbald (1986) produced a generalized stratigraphic succession for the supracrustal rocks (Table 1) and, on the basis of way-up critera, suggested that the sequence faces to the southeast. Since the rocks dip steeply northwest, the sequence is overturned.

Sulphide Lake Area (Studer A, B and C Zones)

A. Studer discovered gold mineralization at Sulphide Lake in 1937 and since then numerous companies including Hudson Bay Mining and Smelting Co. Ltd., Studer Mines Ltd., Westfield Minerals Ltd. and, most recently, the Saskatchewan Mining Development Corporation (SMDC) have been active in the area. Since 1984, SMDC (the operator of the Sulphide Lake Joint venture) has completed a program of 46 drillholes in the vicinity of the Studer showings near the southwest end of Sulphide Lake.

Mapping (1:5,000 scale) has been carried out in the vicinity of the A, B and C zones, as has a study of eight drillholes representative of the mineralization. A total of 128 samples was collected from surface outcrops and trenches, and a further 60 were taken from drill core. The Studer A, B and C zones were chosen for the study because they are typical of the mineralization in the south Sulphide Lake area.

The Studer zones and surroundings are underlain by metavolcanics (unit 2). Felsic (dacitic composition?) pyroclastics and epiclastics, including crystal tuffs, ash tuffs, tuff breccias and reworked tuffs, predominate along with minor felsic flows. Mafic to intermediate volcanics are represented by pillowed and massive flows with some crystal, lithic and ash tuffs. Primary features are rare. Intercalated sediments consist mainly of dark grey-black, fine-grained, well-laminated siltstones and argillites. The argillites are often graphitic and sulphidic, and have been described as lean sulphide

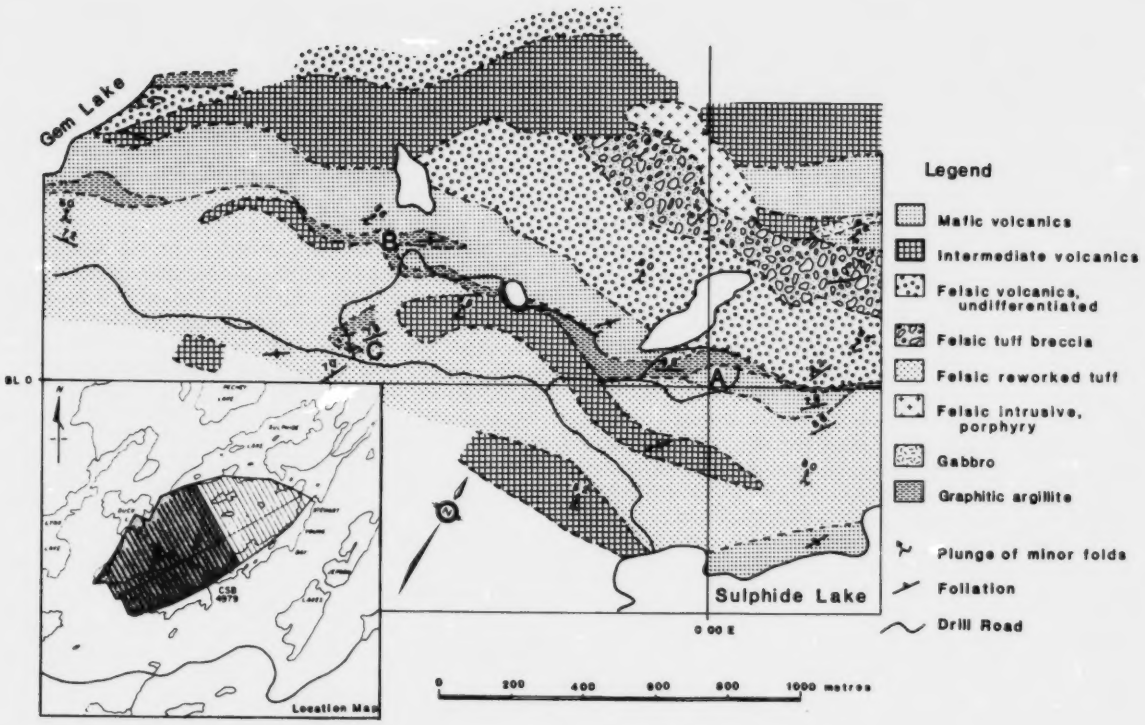

Figure 2 - Geology of the Studer A, B and C zones, Sulphide Lake area.

facies iron formation. Although the sequence shows rapid lateral and vertical facies changes typical of volcanic terrain, it was possible to differentiate several lithological units in the mapped area (Fig. 2).

The area has undergone at least two periods of deformation. The first is marked by rare isoclinal folds (F_1) with axial planes trending northeast and a regional schistosity (S_1) parallel to compositional layering, also trending northeast and dipping moderately to steeply northwest. The second deformational event (F_2) led to the widespread development of minor folds with steep northerly-plunging axes and steeply west- to northwest-dipping axial surfaces. Mafic segregations with bleached alteration haloes are commonly developed parallel to the axial surfaces of F_2 minor folds.

Mapping indicates that the Studer A, B and Chalcopyrite zones occur along the same stratigraphic horizon, namely a dark grey-black, fine-grained, carbonaceous and sulphidic argillite. This unit forms a good stratigraphic marker traceable using geophysical techniques, and other studies (Forsythe, 1971; Coombe, 1984; Sibbald, 1986) have shown that the Studer F, Galena and Caribou showings also occur along it. The mineralization also appears associated with a mafic flow unit and intermediate composition volcaniclastics. All the rocks in the vicinity of the Studer A and B zones show clear evidence of deformation, and alteration. It is possible that the argillite and mafic volcanics took up the bulk of the strain during deformation, leading to 1) the development of folding, crenulation and boudinage on a millimetre scale, and 2) the destruction of any primary textures. Carbonate alteration has locally affected the wallrock, with the introduction of up to 10 percent brown carbonate material (ankerite?) parallel to foliation. Silicification and the development of small millimetre-scale quartz veinlets and stringers, again parallel to foliation, is also prominent. Towards the Chalcopyrite zone, east of the A zone, sericitic alteration and pyrite become important features.

Drilling has indicated that the mineralization in the Studer A and B zones occurs in three distinct layers striking easterly, with a massive felsic volcanic unit forming the structural footwall. Abundant sulphides (up to 20 percent of the rock) accompany the gold mineralization, which is of at least two types:

1) layer-parallel veinlets and stringers of fine-grained pyrite and pyrrhotite;

2) disseminated, euhedral arsenopyrite forming crystals up to 3 mm in diameter scattered throughout the rock.

The Studer C zone, in contrast to the A and B zones, is essentially contained within felsic volcaniclastics, although sulphidic, graphitic argillite does occur in the vicinity. The host rocks form a monotonous and nondescript sequence of light grey, fine-grained, massive to laminated, strongly deformed felsic (dacitic composition?) volcaniclastics with variably developed fine millimetre-scale argillaceous interlayers. The volcanic origin is indicated by the presence of occasional horizons of well-developed crystal tuff containing feldspar crystals up to 7.5 mm in diameter. Within drill core, the feldspar-phyric nature of the unit becomes more apparent and, in some places, recrystallized blue quartz eyes are visible. It has been suggested (R. Chapman, pers. comm.) that this unit is a reworked tuff, thus explaining the sedimentary component noted.

The gold mineralization at the C zone occurs within structurally controlled quartz veins. Two generations were noted:

1) early veins parallel to foliation (S_1), typically boudinaged, usually millimetre to centimetre scale but locally developing to metre scale (e.g., Trench C-1), associated with concordant veinlets and stringers of pyrite and pyrrhotite (up to 2 percent) which becomes massive locally; euhedral disseminated arsenopyrite (up to 5 percent) also common; and

2) late veins within fractures axial planar to the F_2 folds, usually massive metre scale, containing minor pyrite and pyrrhotite along fracture planes. Visible gold was noted in several of these veins in drill core (e.g., DDH SU87/41). The veins probably resulted from brittle failure of the host rocks during F_2 deformation.

Therefore, in contrast to the A and B zones, the mineralization in the C zone appears to have been controlled by brittle fracture of the host rock during deformation, leading to the formation of dilational zones which allowed the influx of mineralizing solutions.

To the north of the mineralized zones, some primary features can be distinguished in the volcanics. A sequence of mafic flows with well preserved pillows (up to 0.5 m diameter) occurs along with a tuff breccia horizon. The tuff breccia is supported by a fine-grained intermediate composition matrix and contains heterolithic (but dominantly felsic composition) fragments up to 40 cm long. The fragments have been stretched out as a result of deformation. A feldspar prophyry intrusive (of granodiorite composition) of limited extent (200 by 400 m), which was also identified in the north of the mapping area, possibly represents a subvolcanic intrusion. To the south of the mineralized zone, the sedimentary component increases and the volcanic rocks grade imperceptibly into epiclastic greywacke sediments. Thus, there is evidence to suggest that the northern part of the area represents a proximal volcanic environment close to an eruptive centre, while the southern part is a distal environment.

On the basis of field relationships, the gold mineralization at the Studer A, B and C zones is definitely epigenetic, occuring within both concordant and discordant quartz veins. However, the ultimate source of the gold remains enigmatic. Suggestions have been made that the zones represent remobilized syngenetic stratiform mineralization associated with the laterally extensive carbonaceous pyrite-pyrrhotite-arsenopyrite-bearing argillite (Coombe, 1984). The carbonaceous argillites reflect a low rate of sedimentation related to a hiatus in volcanism and, in this respect, form a suitable environment for seafloor concentration of metals (Sibbald, 1984). The hydrothermal feeder system, related to volcanic processes, could have been active throughout the depositional history of the supracrustal sequence. When it vented to surface, deposition of metalliferous sediments (i.e., the argillite) would have resulted, while at other times subsurface deposition within suitable structural and physiochemical traps in the volcanic pile could have occurred. An alternate possibility is that the gold has an external origin and was transported into the area by fluids derived either from regional metamorphic dewatering or from the nearby large Contact Lake intrusive complex, again being deposited in favourable physiochemical environments. It is hoped that further studies (fluid inclusions, stable isotopes) will help to resolve this problem.

PAP Lake (A, B and SW) Zones

The mineralized zones at PAP Lake were also examined. SMDC, the operator of the Preview Lake joint venture, is presently carrying out an exploration and drilling program on the property in response to favourable results obtained from previous investigations. The current study was restricted to 12 large trenches (up to 15 m wide and 100 m long) stripped by SMDC during 1986. Outcrop is poor throughout the rest of the area.

Mineralization occurs within shear zones in dioritic to gabbroic sills intruded into dominantly felsic volcaniclastics. The sills are in close proximity (less than 500 m) to the Contact Lake Pluton and are probably genetically related.

Within the SW and A zones, the host rock appears to be of dioritic to leucogabbroic composition and exhibits variations that can be distinguished and correlated between trenches. The rock is grey-green in colour, leuco- to mesocratic, and varies

from a fine-grained microdiorite to a coarse-grained, equigranular diorite. It is characterized by ubiquitous green hornblende porphyroblasts up to 1 cm in diameter and, in places, is feldspar porphyritic (this may be a metamorphic phenomenon; that is, the feldspar crystals may be porphyroblasts). An increase in quartz content to quartz diorite composition is common. Four main units can be distinguished, as follows:

1) Microdiorite - grey, leuco- to mesocratic, fine grained, porphyritic with hornblende and plagioclase porphyroblasts set in a fine-grained matrix.

2) Quartz diorite - grey-green, leucocratic, coarse grained, equigranular, hornblende porphyroblasts common, plagioclase often shows iron oxide staining, 5 to 10 modal percent quartz.

3) Feldspar porphyritic diorite - grey-green, leucocratic, fine to medium grained, porphyritic plagioclase crystals present.

4) Mesodiorite - grey-green, mottled, mesocratic, medium to coarse grained, hypidiomorphic, equigranular, massive.

Sporadic xenoliths of dark grey, fine-grained country rock occur and lithological contacts within the diorite appear gradational.

The shear zones hosting the gold mineralizaton strike consistently northeasterly and are vertical to steeply (dominantly northwest) dipping. The zones are usually several metres wide and the shear sense varies but in most cases appears to be dextral. Many of the shears occur at lithologic contacts and may have developed as a result of competency contrasts. Passing into the shear zones, undeformed diorite becomes progressively foliated and is transformed into a chlorite-biotite schist. A common feature of the zones is that they branch and anastomose around horses of relatively undeformed rock. Joints perpendicular to the shear direction are common.

Two types of quartz veining are present in the shear zones:

1) Concordant veins up to 0.3 m wide, consisting of white, coarsely crystalline, sugary textured quartz with traces of sulphide (arsenopyrite, chalcopyrite) and iron oxide staining along fracture surfaces. In some localities massive arsenopyrite (>50 percent of vein) occurs (e.g., in Trench SW-6) and elsewhere tourmaline is present (e.g., in Trenches SW-2 and A-2). Many quartz veins show evidence of deformation, such as boudinage, indicating that they probably formed as the shear zone was developing.

2) Small quartz veins perpendicular to shear zones which appear to have resulted from brittle fracture, probably synchronous with shearing.

In many localities, quartz veining appears related to mafic (chlorite-rich) pods and segregations which form green selvages around the quartz. A sample of this material was taken for analysis.

Felsic to intermediate composition porphyry dykes are typically present in mineralized outcrops. The relationship of the dykes to the shear zones is not clear. In many instances, they occupy shear zones but are not themselves significantly sheared. Minor shears in the dykes are interpreted as a late reactivation of the zones . All the dykes have a very similar appearance and contain 1 to 2 percent disseminated arsenopyrite, probably related to that associated with gold mineralization.

The trenches at the PAP B zone, approximately 300 m north of the A and SW zones, expose a mixture of rock types which are again cut by northeast-trending mineralized shear zones. The rock types exposed in the B zone trenches are as follows:

1) Gabbro - dark green, fine to medium grained, mesocratic with hornblende porphyroblasts. Although the rock appears to be of gabbroic composition, some of the textures and structures noted indicate that the unit may comprise several mafic flows. Unfortunately, all possible contacts between the flows have been disrupted by shearing so the original relationships cannot be determined.

2) Felsic ash tuff - light grey, fine-grained, laminated rock composed almost entirely of feldspar. Occasionally crystal tuff layers (feldspar crystals up to 5 mm diameter) also occur.

3) Felsic lapilli tuff/tuff breccia - light grey, strongly deformed, matrix-supported tuff containing heterolithic fragments up to 40 cm long. The matrix appears to be more mafic than the fragments. Intercalated with unit 4 on a metre scale.

4) Mafic unit - dark green, fine-grained, chlorite-biotite-actinolite schist, strongly deformed. This unit may be a volcanic horizon or may represent sheared apophyses at the margin of the gabbroic intrusive.

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Project 8732

Metallogenic Studies, Nicholson - Fish Hook Bays Area

by P.W. Peiris[1] and G.R. Parslow[1]

Peiris, P.W. and Parslow, G.R. (1987): Metallogenic studies, Nicholson - Fish Hook Bays area; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

The objective of this study is to document the history of mineralization in the Nicholson - Fish Hook Bays area, historically known for its uranium prospects, which are presently undergoing re-evaluation for their precious metal potential. Samples were collected from old and new workings in the Nicholson 1 (extension), 2 and 4 prospects and the Fish Hook Bay A prospect (Fig. 1), whose geology has been described previously by Christie (1953) and Robinson (1955).

Nicholson Bay - Mineralization is present within a flat-lying sequence of quartzites, phyllites, carbonates (predominantly dolomitic), and a sill-like ultrabasic body. The presence of Athabasca Group rocks lying unconformably on quartzites on the west side of the bay suggests that the outcrop of the crystalline 'basement' defines an erosion surface just below, but very close to, this unconformity. Mineralization is structurally controlled, with evidence of both replacement and open fissure textures, and is hosted predominantly in the carbonates and quartzites.

The history of mineralization is complicated. Initial observations indicate an early premetamorphic sulphide assemblage in pegmatitic diopsidic quartzites and calc-silicates, followed by a pervasive hematization event(s?), then silicification, another hematization (in the form of specularite), and late calcite veining. To date, the relationship of U, Ni, As, Au and Pt to this generalized sequence has not been determined. In particular, silicification events are difficult to identify in the field because of the problems in distinguishing vein quartz from fractured quartzite. An added complication is the presence of cherty alteration in both basement and overlying Athabasca Group sandstones.

Investigations will concentrate on: 1) the samples from the Nicholson 2 and 4 zones, 2) a suite of samples collected on a traverse westwards away from the No. 2 exploration adit, and 3) samples collected on the west side of the bay.

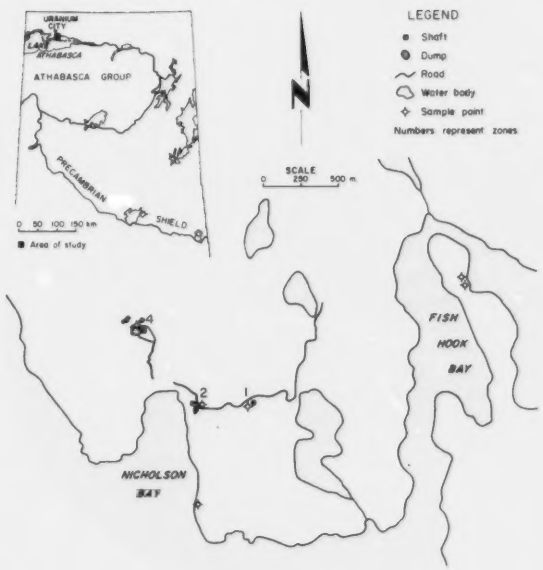

Figure 1 - Sample locations, Nicholson - Fish Hook Bays area.

Fish Hook Bay

In the Fish Hook Bay area, the rock sequence is similar to that at Nicholson Bay except the rocksare more steeply dipping and some of the quartzites are strongly magnetic (interpreted as iron formation). Exposed mineralization is mainly pitchblende with minor sulphides and hematite (which may be oxidized magnetite). All phases show evidence of brecciation and shearing. The samples collected here do not exhibit such clear paragenetic relationships as those of Nicholson Bay and therefore will only be subjected to brief study.

Proposed work will include 1) a petrographic study of thin and polished sections, and 2) multi-element analysis of the various rock types and alteration phases. It is anticipated that we shall be able to show whether or not this mineralization is "unconformity related" (i.e., related to

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unconformity-type uranium deposits within the present day Athabasca Basin).

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Trace Element Geochemistry in the Waddy - Windrum Lakes Area

by C.T. Harper

Harper, C.T. (1987): Trace element geochemistry in the Waddy - Windrum Lakes area; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

Lithogeochemical studies carried out between 1984 and 1986 in conjunction with 1:20,000 scale remapping of the north-central part of the La Ronge Domain (Harper, 1984, 1985, 1986) were designed to characterize the petrogenetic framework of this volcanosedimentary-plutonic terrane. Although major and specific immobile trace element geochemistry has been well documented (Watters, 1984, 1985, 1986; Watters and Pearce, 1986; Harper et al., 1986; Thomas et al., 1987; and Watters et al., 1987), very little information has been released on the more economic-related trace elements, such as Au, Ag, As, Cu, Pb, Zn, Ni, Cr and Mo. This report presents a preliminary summary of the trace element results for the Waddy - Windrum Lakes area (Fig. 1, Tables 1 and 2 and 1:50,000 scale map, in pocket). The purpose is to define regional background values for these elements for the major volcanic and intrusive rock types in the area. Particular emphasis is given to gold because of its current high profile. A more exhaustive statistical treatment of the data will be presented in a future publication.

Geologic Setting

The Waddy - Windrum Lakes area lies in the Early to Middle Proterozoic La Ronge Domain, which in this area comprises parts of the Crew Lake, Central Metavolcanic and MacLean Lake Belts (Fig. 1). The Central Metavolcanic Belt consists of ultramafic to felsic metavolcanics, metavolcaniclastics and metasedimentary rocks, into which a variety of relatively simple to complex multiphase, ultramafic, and mafic to felsic plutons have been intruded. The Crew Lake and MacLean Lake Belts, to the northwest and southeast respectively, comprise psammitic to pelitic metagreywacke gneisses, calc-silicate and varied amphibolitic gneisses with minor intercalated metavolcanics. Both belts have been intruded by generally uniform intermediate to felsic plutons. The transition between the three belts varies from gradational to abrupt, but most commonly is marked by major tectonic breaks, such as the McLennan Lake Tectonic Zone. Field observation and the major and immobile trace element geochemistry indicates that the La Ronge Domain evolved in an island arc environment (Watters, 1984, 1985, 1986; Harper et al., 1986).

Project funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

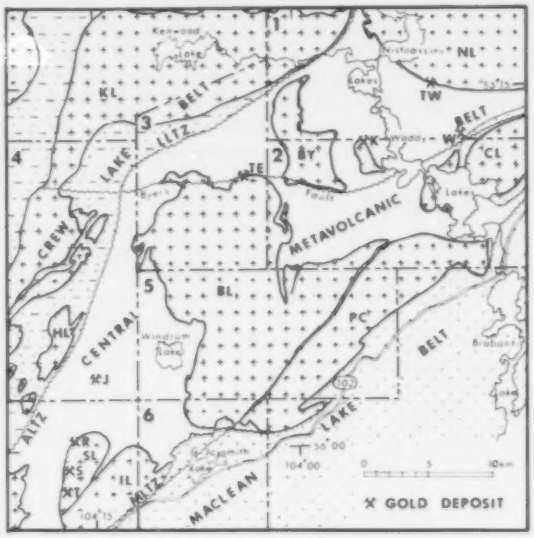

Figure 1 - Index map showing the distribution of the six maps compiled for this report: 1) Waddy North; 2) Waddy South; 3) Tower Lake; 4) Hook Lake; 5) Windrum Lake; and 6) Jaysmith Lake. Crosses indicate intrusive rocks, with the major plutons marked: KL, Kenwood Lake; NLO, Nistoassini Lake; CL, Contact Lake; BY, Boundary Lake; BL, Brindson Lake; PC, Payn Creek; HL, Hook Lake; IL, Island Lake; and SL, Star Lake Plutons. Major tectonic zones include: LLTZ, Looney Lake; ALTZ, Alpat Lake; and MLTZ, McLennan Lake Tectonic Zones. Gold deposits shown are: TW, Twin; W, Weedy; K, Komis and EP; TE, Tower East; J, Jojay; R, Rod-Jolu; S, Star Lake 21 Zone; and T, Tamar.

Presentation of Results

The range and mean values for the 18 trace elements which were routinely analyzed are summarized in Tables 1 and 2. Obviously mineralized samples were not included in this tabulation. It should also be noted that sample populations for several subdivisions are small (as low as eight), and thus the results may not be fully significant statistically.

The metabasalts (Table 1) are subdivided into three groups because of distinctive macroscopic, petrologic and chemical characteristics. Intrusive rock types are subdivided into ultramafic, mafic to intermediate (i.e., gabbro-diorite) and felsic (i.e., granodiorite-granite) groups (Table 2). Although

Table 1 - Summary of Trace Element Data for Volcanic Rocks of the Waddy - Windrum Lakes Area. All values in ppm except Au, which is in ppb. Numbers in parentheses indicate population size.

Element	Lower Waddy Lake Magnesium Basalt		Lower Waddy Lake Fe Tholeiite		All other Basalts		Andesites		Dacites		Rhyolites	
	Range	Mean (8)	Range	Mean (8)	Range	Mean (30)	Range	Mean (17)	Range	Mean (8)	Range	Mean (22)
Ba	14-133	51	41-329	107	13-764*	195(29)	249-819	458	40-651	389	88-1009	484
Sr	65-94	72	81-319	164	59-866	329	213-674	339	153-504	288	69-686	230
Zr	25-55	37	24-110	68	22-136	63	62-220	136	60-181	127	34-311	134
Y	1-8	3	1-24	15	6-26	14	7-30	18	3-27	11	1-38	13
La	0.2-4	1.5	0.6-10	5	3-21	9	11-26	16	7-20	12	1-46	17
Th	0.2-15#	5	0.2-6#	3	1.7-16	4	3-11#	4	3-12#	4	3-19	6
V	97-223	150	147-411	270	126-441	238	43-304	162	53-174	102	1-158	44
Cr	142-2300	855	37-285	157	9-1448	314	1-118	31	1-58	25	1-416*	8(21)
Ni	70-435	186	28-76	56	13-388	98	3-58	25	8-42	1	2-139*	8(21)
Co	27-64	50	27-66	50	22-103	46	6-54	27	7-56	18	1-56	13
Cu	1-235*	49(7)	14-104	50	3-152	71	3-363*	54(15)	8-160*	21(6)	2-197*	20(21)
Pb	-2#	<2	2-3#	<2.4	2-410*	3(28)	2-112*	6.5(15)	2-36#*	4.6(7)	2-35	10
Zn	15-57	32	40-106	74	57-2400*	90(29)	67-164	110	40-541*	72(7)	13-541*	62(21)
Mo	5-10#	<6.6	5-6#	5	5-19#	6.3	5-16#	7	5-7#	5	5-11	5.6
Au	1-89*	10(7)	1.7-10	4.2	0.2-60*	7.7(29)	0.5-29*	7.4(15)	0.5-23	8.1	0.5-40*	6.9(21)
Ag	0.1-0.2#	<0.2	0.1-0.2#	<0.2	0.1-0.5#	<0.2	0.1-2.8#	0.2(14)	0.1-0.3#	0.2	0.1-0.7#	0.2
As	0.2-1.4	0.7	0.2-2.0#	<0.8	0.1-8.	0.6(25)	0.2-6.2	2.0(14)	0.4-14*	2.0(7)	0.1-410*	3.8(21)
Be	1-2#	1.1	1-4#	<1.9	1-5#	2	1-4#	<1.8	-1#	1	1-2#	1
Cd	1-5#	1.6	1-13#	4	1-12#	2.7	1-14#	3.4	1-4#	1.7	1-7#	1.7

- numerous values at or below detection limit for that element
* - obviously anomalous samples(s) omitted from calculation of mean

Table 2 - Summary of Trace Element Data for Intrusive Rocks of the Waddy - Windrum Lakes Area. All values are in ppm except Au, which is in ppb. Numbers in parentheses indicate population size.

Element	Ultramafic		Mafic - Intermediate		Felsic (>63% SiO_2)	
	Range	Mean (20)	Range	Mean (25)	Range	Mean (50)
Ba	3-67	21	53-1950	569	330-1173	695
Sr	2-316*	7(18)	106-1254	622	109-1124	641
Zr	9-112	39	20-196	92	18-181	76
Y	1-10	1.6	2-31	15	1-31	7
La	1-7	2	4-59	22	3-35	15
Th	3-13	5.6	3-12	6	3-19	7
V	42-225	94	16-264	155	2-122	43
Cr	226-5300	2966	11-3600*	370(24)	1-171	31
Ni	87-1417	670	14-325	96	2-53	14
Co	46-120	84	7-77	36	1-95	18
Cu	1-125*	7(19)	1-150	32	1-114	10
Pb	-2#	2	2-15	4	2-55	10
Zn	18-87	55	31-116	79	21-100	46
Mo	5-19	6	5-13	<6	5-23#	5.6
Au	1.0-108*	2.4(19)	0.7-23	4.2	0.7-29	3.7
Ag	0.2-0.7#	0.2(17)	0.1-0.5#	<0.2	0.1-0.7#	0.2
As	0.2-11*	1.6(18)	0.2-2.2	0.7	0.2-12	0.9
Be	-1#	<1	na	na	na	na
Cd	1-5	2.1	na	na	na	na

- numerous values at or below detection limit for that element
* - obviously anomalous sample(s) omitted from calculation of mean
na - data not available

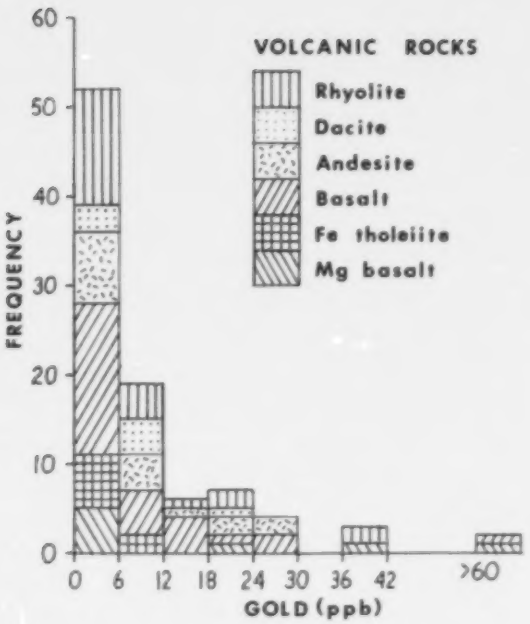

Figure 2 - Combined histogram for all volcanic rocks.

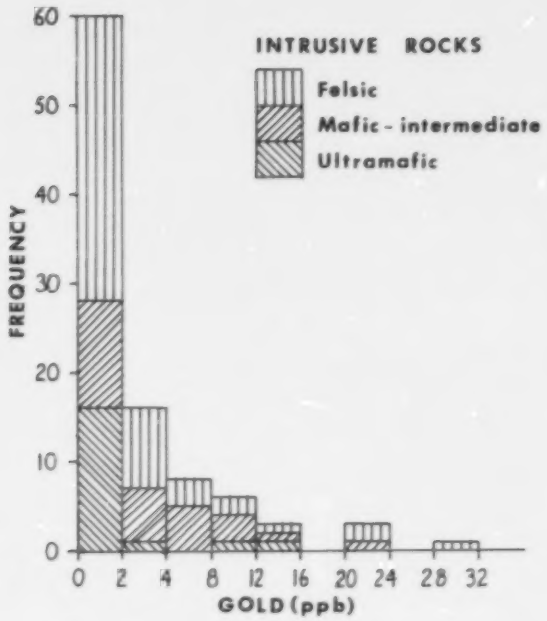

Figure 3 - Combined histogram for all intrusive rocks.

some of the intrusive phases have very distinctive chemical signatures, the use of a few subdisions is preferred in calculating regional background values. Further geochemical analysis of the major plutonic bodies is underway.

Average gold concentrations in the volcanics are generally about twice the average in the corresponding intrusive rock types. Copper and zinc concentrations are generally greater in the volcanics than their intrusive equivalents, whereas the reverse is the case for Ba and Sr (except for the ultramafic intrusives). The other elements do not show such well defined trends.

Histograms for gold, showing the combined effect for all the volcanic (Fig. 2) and intrusive (Fig. 3) rock types, reveal highly skewed background populations. In both cases, almost 60 percent of the samples contain less than 6 ppb and 2 ppb Au, respectively, for the volcanic and intrusive rocks. For volcanic rocks, 20 ppb Au is probably anomalous, whereas 15 ppb Au is considered anomalous for intrusive rocks. These values are used to distinguish anomalous samples on the accompanying map.

The 1:50,000 scale map shows the sample locations on a simplified geological base (derived from the original six 1:20,000 scale geological maps), which outlines the various intrusive rocks and the boundaries of the Central Metavolcanic Belt. Major faults, gold deposits and prospects, mineral occurrences and areas of quartz veining and alteration are also depicted. Analytical results for nine elements, including Cu, Pb, Zn, Ni, Cr, Mo, Au, As and Ag, are listed on the maps for each sample location. For Mo and Ag, only those values exceeding the detection limits of 5 ppm and 0.2 ppm, respectively, are shown. Samples containing high background and anomalous concentrations of gold are shaded appropriately.

Discussion

Gold exploration in the La Ronge Domain is intensifying. Emperical observations suggest that the most common visual guides to gold mineralization, apart from visible gold, include a combination of the following:

1) the presence of sulphides, typically pyrite but locally pyrrhotite, chalcopyrite, galena and arsenopyrite, may be guides to elevated gold concentrations;

2) the presence of quartz veining, associated shearing and, in most cases, wall rock alteration of varying intensity; and

3) the close proximity to intrusive rocks; gold occurs either within or adjacent to them.

Target areas associated with pyrite are of several types, including 1) carbonaceous meta-argillites,

2) sulphide-facies iron formation, 3) metamorphic aureoles surrounding the late silicic plutons such as the Round Lake, Windrum Lake and Bryenton Lake Stocks, 4) in and adjacent to many faults/shear zones, and 5) in many of the felsic metavolcanic rocks, particularly those west of Lower Waddy Lake.

Geochemically, gold is its own best pathfinder element. In some places, elevated copper and arsenic concentrations accompany higher and/or anomalous gold concentrations, but neither element could be used alone as a guide to gold mineralization in this region. None of the other trace elements appear to show any strong correlation to gold mineralization.

Even with the limited data base available, several zones of anomalous gold concentrations are indicated. These include:

1) the area northeast and southwest of the Weedy Lake gold deposits;

2) a broad but discontinuous zone south and paralleling the Byers Fault, extending from near the narrows on Waddy Lake west-southwest to Oven Lake; and

3) the area surrounding the Windrum Lake Stock.

Single-site gold anomalies may also be important targets for gold mineralization. Some of the better anomalies include:

1) the 108 ppb value (sample 84-33) west of the north end of Greenhill Lake, hosted by a sheared ultramafic dyke or sill;

2) sample 84-1042, located at the north end of a small island in Upper Waddy Lake, gave 1200 ppb Au in diorite of the Dog Creek Stock adjacent to the trace of an east - west structure (repeat analysis was not done);

3) a pyritic quartz vein (sample 85-518), near the sheared contact of a large basaltic xenolith in the Boundary Lake Pluton, 3 km west of Round Lake, contains 80 ppb Au;

4) a coincident copper (8000 ppm) and gold (200 ppb) anomaly (sample 85-73) on the west shore at the south end of Redhill Lake, hosted by a sheared siliceous pyrite-pyrrhotite-bearing horizon (sulphide-facies iron formation) within a succession of ultramafic volcanics and intrusives;

5) a 100 ppb Au anomaly (sample 85-569) on the east side of Partington Lake about 200 m south of the Byers Fault occurs in a pyritic quartz vein in sheared diorite along a north-northeast-trending fault;

6) a 117 ppb Au anomaly (sample 86-2161), 1 km east of the south end of Ahol Lake, occurs in a magnetite-bearing garnet-hornblende rock (oxide-silicate-facies iron formation); and

7) a non-in situ Mo (5000 ppm), Cu (4500 ppm) and Au (190 ppb) anomaly (sample 86-608) was derived from chalcopyrite-molybdenite-pyrite-bearing quartz vein material found at an old prospecting camp near the west end of a small lake 1 km north of Island Lake; the source of this material is not known.

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Project 8702

Geochemistry of Basaltic Rocks in the East Amisk Area

by G.R. Parslow[1]

Parslow, G.R. (1987): Geochemistry of basaltic rocks in the East Amisk area; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

Previous studies of the Flin Flon volcanic belt in Saskatchewan (Gaskarth and Parslow, in press; Parslow, 1987; Parslow and Gaskarth, 1984, 1986, in press; Parslow et al., 1986) indicate that the majority of the rocks have island arc affinities. However, the East Amisk data exhibit clear polymodality in the distributions of various trace elements, in particular the immobile elements.

An example of this polymodality is shown in the histogram of TiO_2 (Fig. 1). The immobile elements Nb, Sr, Y and Zr exhibit strong positive correlations with TiO_2 (cf. Tables 1 to 3) and, as such, do not display geochemical coherence. For example, if the variations were solely a function of differentiation

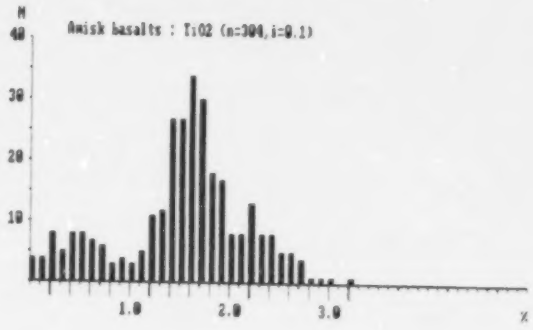

Figure 1 - Histogram of TiO_2 distribution in basaltic rocks of the East Amisk area. The three subfiles referred to in the text were derived by taking low-Ti basalts as 0 to 1 percent, mid-Ti basalts as 1 to 2 percent and high-Ti basalts as greater than 2 percent TiO_2.

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Table 1 - Summary Statistics of East Amisk Low-Ti Basalts (71 Samples).

	MEAN	S.D.	MIN	MAX	GMEAN	GM-S.D.	GM+S.D.	LOGMEAN	LOG S.D.
SiO2	49.11	3.16	38.31	52.82	49.00	45.77	52.46	3.8918	0.0683
TiO2	0.50	0.28	0.01	0.99	0.38	0.14	0.99	-0.9730	0.9589
Al2O3	14.66	3.82	0.32	20.99	12.99	6.33	26.65	2.5643	0.7104
Fe2O3	3.16	1.51	0.83	8.24	2.83	1.76	4.55	1.0420	0.4742
MnO	0.17	0.07	0.08	0.37	0.16	0.11	0.23	-1.8614	0.3738
FeO	7.82	2.29	1.84	11.92	7.40	5.14	10.66	2.0014	0.3647
MgO	11.50	8.21	3.09	44.21	10.01	6.22	16.12	2.3040	0.4761
CaO	10.04	3.40	0.27	22.61	9.20	5.40	15.67	2.2195	0.5324
Na2O	2.22	1.06	0.21	4.61	1.86	0.92	3.77	0.6205	0.7878
K2O	0.68	0.79	0.01	3.35	0.38	0.12	1.22	-0.9791	1.1782
P2O5	0.13	0.12	0.04	0.82	0.10	0.05	0.19	-2.2829	0.6441
H2O-	0.14	0.10	0.01	0.50	0.11	0.05	0.24	-2.1953	0.7602
LOI	4.56	5.64	0.25	32.40	2.84	1.13	7.13	1.0453	0.9187
Ba	171.67	307.44	1.01	1589.43	31.12	3.22	300.71	3.4378	2.2683
Cr	682.65	1515.80	1.00	7582.38	178.92	25.83	1131.14	5.1412	1.8898
Cu	86.87	100.47	1.49	410.00	43.39	11.63	161.85	3.7703	1.3164
Nb	3.16	1.32	1.47	6.89	2.92	1.98	4.31	1.0715	0.3894
Ni	193.85	419.03	14.48	2192.56	87.87	30.42	249.25	4.4667	1.0517
Pb	9.31	30.71	1.00	169.09	2.77	0.95	8.10	1.0203	1.0712
Rb	12.79	13.03	1.13	65.99	8.13	3.14	21.02	2.0954	0.9582
Sr	158.40	135.75	3.39	629.03	113.00	47.40	272.74	4.7344	0.8741
Th	2.66	1.59	1.00	7.10	2.21	1.19	4.11	0.7939	0.6207
U	1.52	1.60	1.00	14.52	1.29	0.82	2.02	0.2539	0.4488
V	272.14	215.99	35.70	1521.11	229.41	131.90	399.02	5.4355	0.5535
Y	14.55	7.62	1.13	29.96	11.50	5.19	25.07	2.4497	0.8033
Zn	97.07	100.15	19.36	1491.05	66.73	34.00	130.96	4.2007	0.6742
Zr	36.50	23.56	6.99	181.62	29.06	14.26	59.24	3.3694	0.7122
Au	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0000	0.0000

Table 2 - Summary Statistics of East Amisk Mid-Ti Basalts (203 Samples).

	MEAN	S.D.	MIN	MAX	GMEAN	GM-S.D.	GM+S.D.	LOGMEAN	LOG S.D.
SiO2	49.11	2.66	38.85	52.86	49.03	46.13	52.11	3.8924	0.0689
TiO2	1.59	0.22	1.00	1.99	1.57	1.36	1.82	0.4526	0.1467
Al2O3	14.96	1.39	8.95	20.49	14.90	13.59	16.34	2.7014	0.0924
Fe2O3	3.76	1.47	0.80	13.36	3.52	2.42	5.11	1.2572	0.3735
MnO	0.19	0.07	0.09	0.52	0.18	0.12	0.25	-1.7393	0.3579
FeO	8.77	1.74	1.30	13.53	8.55	6.78	10.91	2.1462	0.2435
MgO	7.92	1.79	3.41	19.79	7.73	6.15	9.71	2.0447	0.2289
CaO	10.47	3.49	2.17	41.00	9.96	7.18	13.84	2.2990	0.3283
Na2O	2.57	0.83	0.24	4.74	2.39	1.54	3.71	0.8704	0.4407
K2O	0.50	0.66	0.05	4.71	0.32	0.13	0.77	-1.1417	0.8805
P2O5	0.15	0.11	0.06	0.85	0.13	0.08	0.21	-2.0526	0.4819
H2O-	0.15	0.16	0.01	1.69	0.10	0.04	0.26	-2.2816	0.9488
LOI	4.00	3.61	0.41	24.70	3.13	1.52	6.44	1.1414	0.7289
Ba	125.56	220.00	1.02	2192.94	49.41	9.60	254.42	3.9002	1.6388
Cr	130.38	94.48	1.02	773.65	89.71	27.06	297.35	4.4965	1.1984
Cu	83.72	45.59	7.57	417.46	72.32	40.43	129.34	4.2810	0.5814
Nb	7.48	2.32	3.96	27.59	7.15	5.57	9.17	1.9666	0.2493
Ni	66.59	26.61	4.25	270.78	60.49	36.30	100.80	4.1025	0.5106
Pb	3.14	4.13	0.99	54.27	2.38	1.20	4.70	0.8654	0.6826
Rb	10.10	12.61	2.07	128.96	7.55	3.89	14.62	2.0209	0.6615
Sr	239.36	111.21	22.34	1070.00	215.58	131.66	352.98	5.3733	0.4931
Th	2.38	1.40	0.99	6.53	2.02	1.14	3.58	0.7047	0.5705
U	1.62	1.11	0.99	8.25	1.42	0.89	2.27	0.3492	0.4695
V	330.59	113.30	3.00	986.67	309.51	198.46	482.68	5.7350	0.4444
Y	28.69	5.37	15.48	59.54	28.21	22.49	33.88	3.3398	0.1830
Zn	97.62	24.97	38.90	341.85	95.32	77.13	117.79	4.5572	0.2117
Zr	101.58	18.01	49.85	200.96	100.06	84.09	119.07	4.6058	0.1739
Au	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0000	0.0000

Table 3 - Summary Statistics of East Amisk High-Ti Basalts (72 Samples).

	MEAN	S.D.	MIN	MAX	GMEAN	GM-S.D.	GM+S.D.	LOGMEAN	LOG S.D.
SiO2	48.75	2.67	35.83	52.68	48.67	45.93	51.59	3.8852	0.0581
TiO2	2.41	0.34	2.01	4.31	2.39	2.11	2.71	0.8728	0.1258
Al2O3	15.38	1.52	13.32	20.03	15.23	13.88	16.72	2.7233	0.0931
Fe2O3	4.88	1.51	1.45	8.28	3.81	2.63	5.54	1.3389	0.3727
MnO	0.19	0.08	0.03	0.45	0.17	0.11	0.26	-1.7627	0.4189
FeO	8.71	1.96	3.20	16.69	8.49	6.73	10.71	2.1387	0.2323
MgO	6.96	1.34	3.85	12.07	6.84	5.66	8.26	1.9222	0.1993
CaO	10.87	2.44	2.41	15.53	9.69	7.14	13.16	2.2718	0.3059
Na2O	2.71	1.24	0.41	6.64	2.48	1.41	4.09	0.8745	0.5339
K2O	0.65	0.61	0.07	2.98	0.46	0.21	1.04	-0.7784	0.8122
P2O5	0.18	0.09	0.08	0.49	0.17	0.11	0.25	-1.7930	0.4108
H2O-	0.15	0.11	0.01	0.65	0.12	0.05	0.27	-2.1413	0.8474
LOI	3.82	2.66	0.97	15.10	3.06	1.55	6.04	1.1198	0.6802
Ba	159.18	140.37	1.03	591.85	102.16	33.67	309.99	4.6265	1.1100
Cr	123.29	80.54	1.03	383.03	85.27	26.68	272.49	4.4458	1.1618
Cu	78.00	44.86	11.03	282.79	66.75	36.95	120.58	4.2018	0.5914
Nb	13.39	5.86	6.95	41.32	12.48	8.74	17.83	2.5243	0.3566
Ni	62.25	24.71	10.74	137.69	57.44	37.67	87.58	4.0587	0.4219
Pb	3.30	2.15	1.01	10.45	2.68	1.38	5.21	0.9852	0.6657
Rb	11.68	8.57	2.05	47.85	9.52	5.08	17.81	2.2530	0.6270
Sr	281.44	128.91	27.47	783.14	250.19	146.43	427.47	5.5222	0.5357
Th	2.43	1.51	1.00	6.39	2.03	1.11	3.71	0.7068	0.6836
U	1.91	1.73	1.00	13.05	1.57	0.98	2.74	0.4583	0.5563
V	364.95	127.87	151.37	669.20	343.60	241.82	488.23	5.8395	0.3513
Y	36.24	7.11	21.28	59.84	35.57	29.31	43.18	3.5716	0.1938
Zn	113.24	26.67	52.43	222.29	110.41	88.13	138.32	4.7042	0.2254
Zr	165.86	36.91	103.35	338.94	162.13	131.78	199.46	5.0884	0.2072
Au	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0000	0.0000

within a single suite of basalts, then, as TiO_2 increases, Nb, Sr, Y and Zr should decrease. A better explanation of the observed correlations is that the low-immobile element group is typically island arc, whereas the mid- and high-immobile element rocks are of oceanic affinity.

A further complicating factor is that the 'typical' island arc sub-file (i.e., low-Ti basalts) exhibits rather high Cr and Ni averages with extremely large standard deviations, suggesting an affinity of this group with the ultrabasic rocks present in the area. Thus, this group may be 'komatiitic' rather than true 'island arc' in affinity.

Notwithstanding these problems, Fig. 2 illustrates the distribution of these three groups of basalts on a log Ti - log Zr discriminant diagram (Pearce et al., 1981); similar separations are observed on Ti-Zr-Y, Ti-Zr-Sr and Y-Cr discriminant diagrams (Pearce and Cann, 1973; Pearce, 1982) not shown here.

The present study is aimed at collecting some REE analyses of typical samples of the three groups of basalt in an attempt to further quantify the presence of oceanic material (i.e., ocean floor, ophiolite or back arc rift) and presumed island arc rocks within the East Amisk area. Although the analyses have not been received yet, some preliminary data on REE elements, using XRF analysis, suggest that REE patterns are compatible with the presence of oceanic basalts in the East Amisk area. Recent work by Symes (pers. comm.) in the area of Athapapuskow Lake, Manitoba indicates the presence of similar oceanic rocks probably underlying the typical island arc rocks of the main Flin Flon volcanic belt. This is encouraging, because the East Amisk oceanic lavas are bounded to the west by Amisk Lake, to the south by the Phanerozoic cover, and to the north and east by later granitic intrusions and thus their true relationships to the other volcanics in the region are difficult to elucidate.

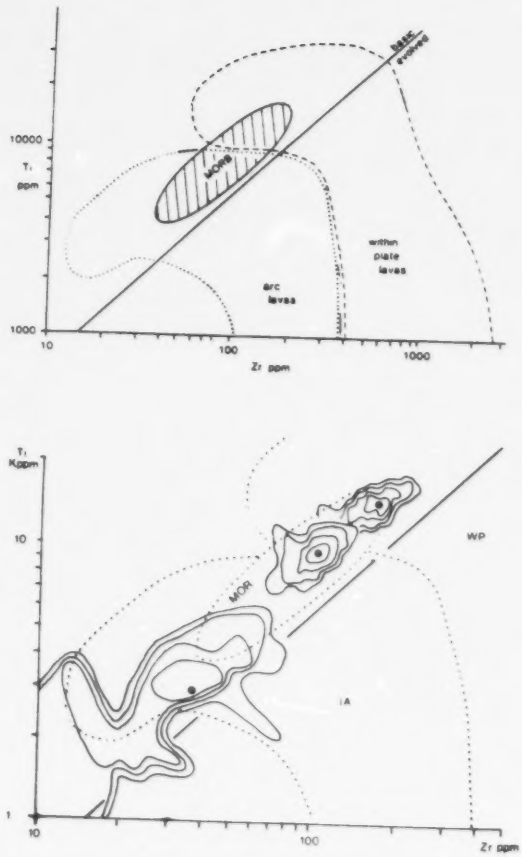

Figure 2 - The upper diagram illustrates the various fields of volcanic rocks as defined by the log Ti - log Zr diagram (Pearce, 1982). The lower diagram illustrates the East Amisk subfiles (low-, mid- and high-Ti basalts) on the same diagram. The dots represent the average file values and the contours are 0.5, 1.0, 1.5 and 2.0 standard deviations from the mean value; thus, the contours also represent, outwards, 34 percent, 68 percent, 86 percent, and 95 percent of the data in a given file.

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Project 8721

Geochemistry of Plutonic Rocks in the Central Metavolcanic Belt, La Ronge Domain

by B.R. Watters[1]

Watters, B.R. (1987): Geochemistry of plutonic rocks in the Central Metavolcanic Belt, La Ronge Domain; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

A geochemical study of metavolcanic and plutonic rock units of the Central Metavolcanic Belt, La Ronge Domain has been carried out as a complement to the remapping program conducted by C.T. Harper and D.J. Thomas (Harper, 1984, 1985, 1986; Thomas, 1984, 1985, 1986, this volume). Earlier geochemical work was concerned primarily with the metavolcanic units (Watters, 1981, 1984, 1985, 1986; Watters and Armstrong, 1985; Watters and Pearce, in press). Recent studies have been aimed at the geochemical characterization of the plutons, their mode of origin, mineralization potential and relationships to the metavolcanic units (Watters, 1985, 1986; Harper et al., 1986; Thomas and Watters, 1987).

Geochemical Analyses and Data Processing

During the current project year geochemical work has been directed mainly toward the following:

1) Major and trace element analysis of 53 samples from plutons in the Esmay Lake - Onipoowuk Lake area (i.e., Dreaver Lake Stock, Moir Lake Pluton, Kruger Lake Pluton, Bernaski Bay Pluton, Hayman Lake Intrusion and Onipoowuk Pluton). A further 164 samples from these bodies, as well as the Nipew Lake Basic Intrusion, the Bandur Lake Pluton and the Bartlett Lake Intrusion, have been prepared and will shortly be analyzed.

2) A detailed geochemical and petrological study of the Brindson Lake Pluton has been initiated. A preliminary suite of 38 samples from five plutonic phases has been analyzed for major and trace elements and analysis of a further 150 samples representative of all eight phases is in progress. REE will be determined for selected samples and a Sr isotope study is also planned.

As reported in Watters (1985), geochemical data for this project are presently stored in a Hewlett-Packard Series 80 microcomputer filing system, and software has been developed for data manipulation and graphic representation. Software is now available to generate geochemical maps of plutons. Figs. 1 and 2 show the distribution of SiO_2 and CaO in the Star Lake Pluton. Both elements illustrate zonation in the pluton, with concentrations of silica and calcium increasing and decreasing respectively from the outer to the central zone.

Brindson Lake Pluton

The Brindson Lake Pluton in the Windrum Lake area is a multiphase intrusion, each phase of which shows compositional zoning ranging from simple concentric to asymmetric (Harper, 1986). In terms

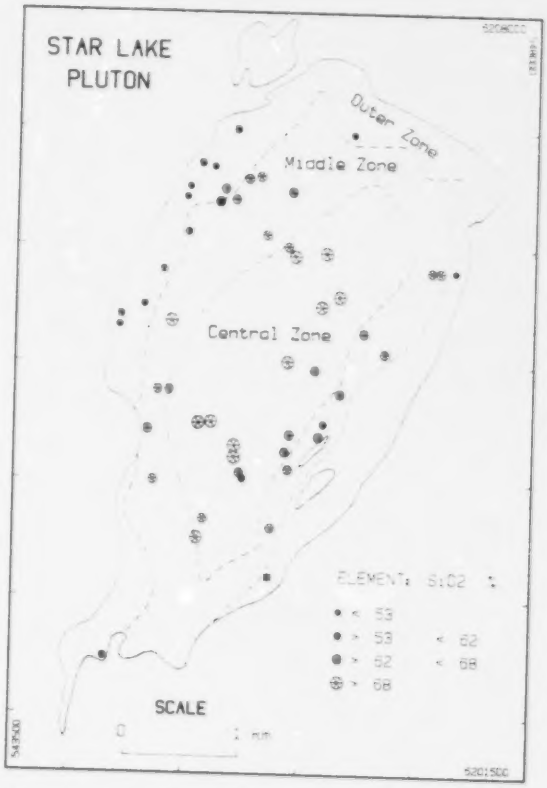

Figure 1 - Computer-generated map of the Star Lake Pluton showing the distribution of SiO_2 content. Dashed lines represent approximate positions of zone boundaries as suggested by Thomas (1987, pers. comm.).

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Project contracted to the University of Regina with funds provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89. Some aspects of the analytical work were funded by a research grant from the Saskatchewan Research Council.

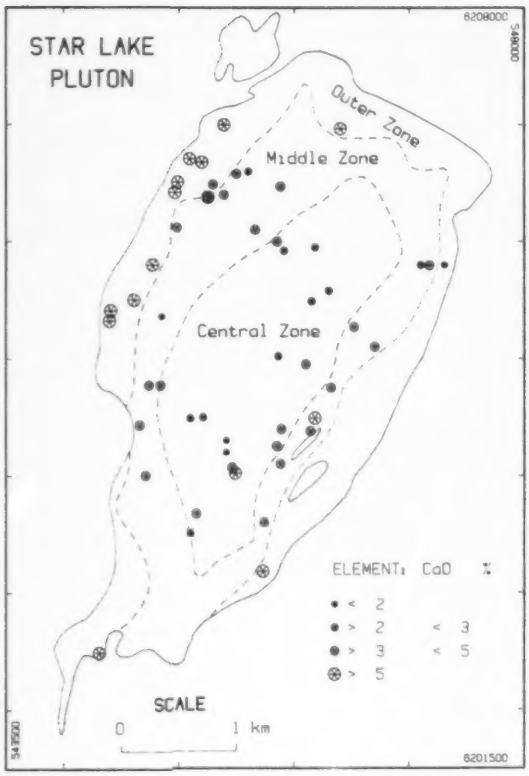

Figure 2 - Computer-generated map of the Star Lake Pluton showing the distribution of CaO content. Dashed lines represent approximate positions of zone boundaries as suggested by Thomas (1987, pers. comm.).

of the classification proposed by Thomas (1985) and Harper et al. (1986) for plutons in the Central Metavolcanic Belt, the Brindson Lake Pluton is a Type 1 pluton (composite and/or zoned type), in this respect similar to the Star Lake Pluton. However, the multiphase character and zonation of the phases is more complex than in the Star Lake body.

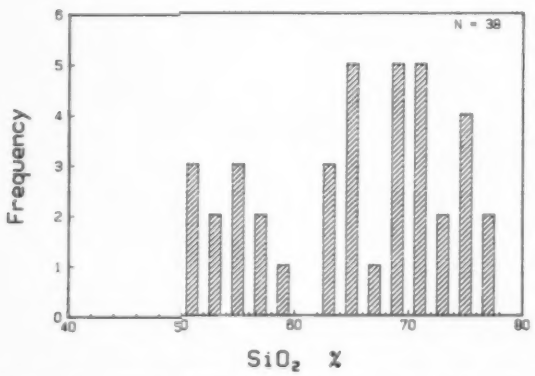

Figure 3 - SiO_2 histogram for the Brindson Lake Pluton.

Harper (1986) has named a number of component phases for the pluton which range compositionally from gabbro and diorite through monzonite, granodiorite and granite, to leucogranite. Geochemical data for representative phases are listed in Table 1. Silica content ranges from about 50 to 77 percent, with suggestion of, on the limited number of samples analyzed, compositional bimodality (Fig. 3).

The wide range of rock types in the Brindson Lake Pluton is further evident from relationships between the alkalies, total Fe and MgO (Fig. 4). Individual phases comprise coherent and overlapping compositional fields that collectively define a

Table 1 - Analytical Data for Samples Representative of Major Phases of the Brindson Lake Pluton.

	2119	2110	82	H26-1	2299	2044	411
SiO_2	51.20	64.00	55.20	57.40	68.60	70.00	74.90
TiO_2	1.04	.90	.64	.63	.31	.40	.15
Al_2O_3	19.40	18.10	14.10	16.00	16.60	13.70	13.10
FeO*	7.88	5.23	7.21	6.37	2.51	3.12	1.16
MnO	.12	.09	.14	.12	.05	.06	.03
MgO	6.15	2.22	8.13	4.87	1.30	1.71	.65
CaO	8.51	4.72	8.76	6.85	4.86	4.44	1.56
Na_2O	3.23	3.99	3.05	4.15	4.63	4.30	5.41
K_2O	.44	1.29	.47	1.24	.56	1.36	2.21
P_2O_5	.04	.34	.18	.17	.13	.13	.10
l.o.i.	.60	.30	.50	.70	.60	.60	.50
	98.61	101.18	98.38	98.50	100.15	99.82	99.77
Sr	614	539	578	501	751	620	751
Y	14	18	13	13	6	7	3
Zr	72	150	45	36	22	45	68
Pb	4	2	2	6	4	6	9
Th	3	6	5	9	3	10	3
Ni	62	23	103	32	10	15	6
Cu	21	19	36	18	2	6	1
Zn	70	75	80	68	39	55	30
Ba	211	568	166	322	343	409	840
Co	40	20	41	38	7	15	10
Cr	50	37	515	129	23	30	9
V	193	74	197	162	45	59	12
La	10	24	7	11	6	26	10
Au	1.3	.8	1.1	8.7	.7	.7	.7
As	.5	.2	1.1	.3	.5	1.9	.7

Oxides in weight percent; FeO* = total Fe as FeO; Au in ppb; all other trace elements in ppm.

2119 Gabbro/diorite, Tower Phase.
2110 Granodiorite, Tower Phase.
82 Diorite, Dicus Lake Phase.
H26-1 Quartz diorite, Southern Phase.
2299 Granodiorite, Southern Phase.
2044 Granite, Brindson Phase
411 Leucogranite, Severson Leucogranite Phase.

calk-alkaline trend, typical of plutons in the Central Metavolcanic Belt. Here, also, there is a suggestion of overall compositional bimodality. The Tower Phase is distinctly bimodal due to the presence of a basic marginal zone and a dominant monzonite-granodiorite inner zone. The Severson Leucogranite Phase is the most acidic, defining a distinctive field of compositions with relatively high (Na+K)/(Mg+Fe) ratios. A plot of SiO_2 vs. Zr+Y (Fig. 5) indicates the following:

1) While the overall SiO_2 content for the pluton ranges from about 50 to 77 percent, individual phases show overlapping but far more restricted ranges of this element.

2) The Tower Phase, probably the oldest in the complex, shows a very broad range of composition in terms of both silica and Zr+Y, and is compositionally distinct from the other phases, having higher Zr+Y contents. Furthermore, compositions for this phase do not appear to define a trend. Although the data are not fully representative, at least some of the compositional characteristics of this early phase may be attributed to contamination, a suggestion supported by field evidence (Harper, 1986). This phase may also derive from a separately evolved magma batch.

3) The distribution of compositions for the Dicus Lake, Southern, Brindson and Severson Leucogranite phases define a trend of increasing silica content with a slight increase in Zr+Y. Field evidence suggests the phases may have been emplaced in the order listed above (Harper, 1986; 1987, pers.comm.), indicating a progressive fractionation towards more felsic compositions.

This trend is entirely consistent with that noted for other multiphase or zoned plutons in the Central Metavolcanic Belt. For example, the Star Lake Pluton shows a similar progression from an early outer zone relatively low in silica, to a later central zone relatively high in silica (Fig. 6). This trend has been attributed primarily to fractionation prior to final emplacement (Watters, 1985; Harper et al., 1986). An important difference between the Brindson Lake Pluton and the Star Lake Pluton (cf. Figs. 5 and 6) is the increase in Zr+Y with increasing SiO_2 in the former, whereas the Star Lake Pluton shows a general decrease in Zr+Y with increasing acidity. Zr+Y values for the main phases in the Brindson Lake Pluton are also significantly lower than for the Star Lake Pluton; the latter is similar to the Tower Phase in this respect. These characteristics may be due in part to differences in the fractionating mineral phases in these intrusions.

Barium is also a strongly fractionated element in the Brindson Lake Pluton, showing a progressive increase in concentration, concomitant with the increase in silica content, from the Dicus Lake Phase through the Southern and Brindson Phases to the Severson Leucogranite Phase (Fig. 7). Ba values in the Tower Lake Phase are highly variable, further reflecting the variable and possibly contaminated composition noted above.

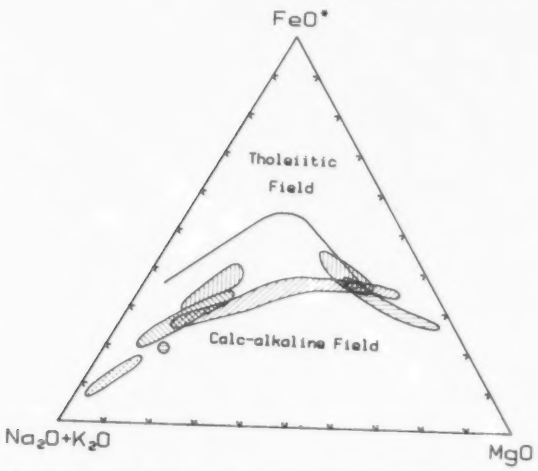

Figure 4 - AFM plot showing compositional fields for major phases of the Brindson Lake Pluton. Key: Tower Phase; Brindson Phase; Southern Phase; Dicus Lake Phase; Severson Leucogranite Phase. Tholeiitic - calc-alkaline boundary from Irvine and Barager (1971).

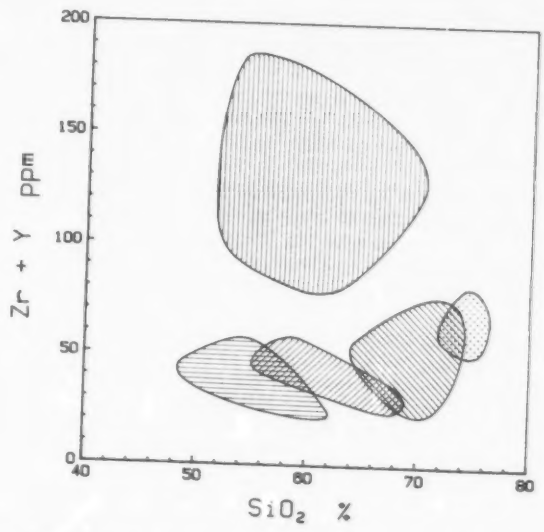

Figure 5 - Plot of SiO_2 vs. Zr+Y showing compositional fields for main phases of the Brindson Lake Pluton. Key as for Fig. 4.

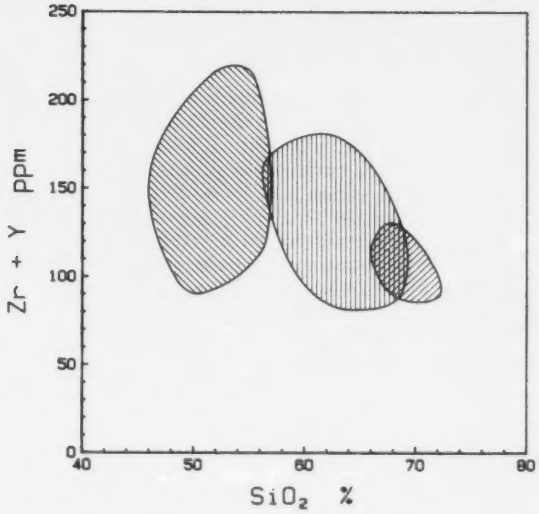

Figure 6 - Plot of SiO_2 vs. Zr+Y showing compositional fields for zones of the Star Lake Pluton. Key: ▨ Outer Zone; ▥ Middle Zone; ▨ Central Zone.

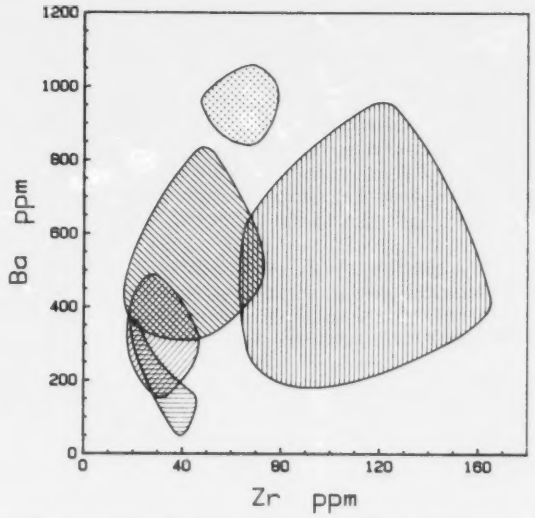

Figure 7 - Plot of Ba vs. Zr showing compositional fields for main phases of the Brindson Lake Pluton. Key as for Fig. 4.

By comparison, Ba concentrations in the Star Lake Pluton are generally significantly higher than those for the Brindson Lake Pluton. Furthermore, there is little evidence of any fractionation of this element, except possibly in the latest central zone (Fig. 8). In summary, there are significant differences in the petrologic evolution of these two intrusions and further geochemical work on the Brindson Lake Pluton may help resolve these differences.

Plutons in the Esmay Lake - Onipoowuk Lake Area

As the geochemical study of intrusions in this area is still in the preliminary stages, only a few general observations may be made at this time.

An AFM plot (Fig. 9) indicates that, with the possible exception of the Hayman Lake intrusion, plutons from this area are of calc-alkaline character, similar to other plutons in the Central Metavolcanic Belt.

The Hayman Lake intrusion displays an apparently transitional, mildly tholeiitic to calc-alkaline affinity similar to many of the metavolcanic units in the La Ronge Domain. Notably, the Bernaski Bay Pluton is in general slightly more iron-enriched than the other calc-alkaline plutons. The compositional range of plutons in this area is variable: the Dreaver Lake and Onipoowuk bodies are largely acidic and the Kruger Lake and Moir Lake plutons are intermediate to acidic, whereas the Bernaski Bay Pluton includes a wide range of rock types from basic through to acidic.

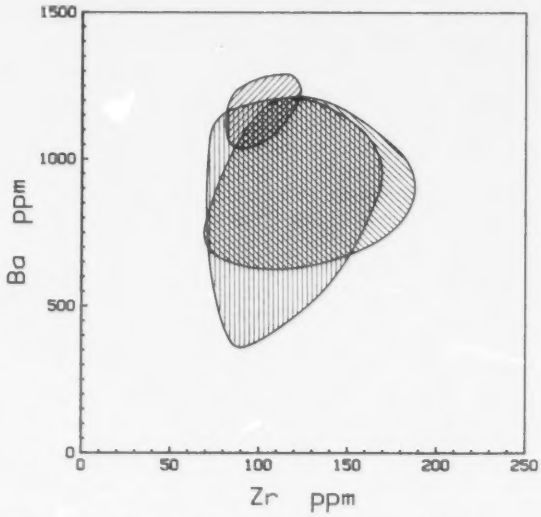

Figure 8 - Plot of Ba vs. Zr showing compositional fields for zones of the Star Lake Pluton. Key as for Fig. 4.

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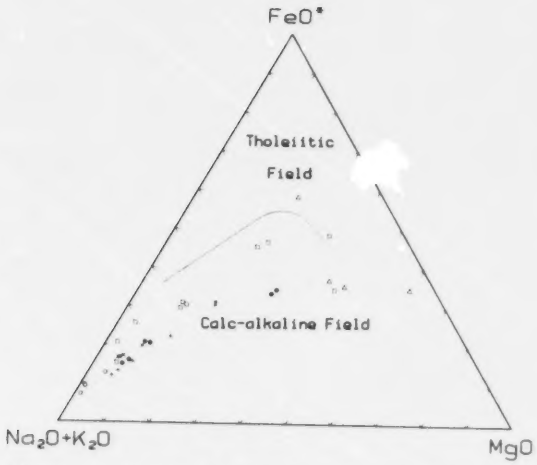

Figure 9 - AFM plot for rocks from plutons in the Esmay Lake - Onipoowuk Lake area. Open circles, Dreaver Lake Stock; filled circles, Moir Lake Pluton; crosses (+), Kruger Lake Pluton; stars (x), Onipoowuk Lake Pluton; squares, Bernaski Bay Pluton; triangles, Hayman Lake Intrusion. Tholeiitic - calk-alkaline boundary from Irvine and Barager (1971).

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Project 8708

Sampling for K-Ar Dating in the La Ronge Domain

by Michael Bikerman[1]

Bikerman, M. (1987): Sampling for K-Ar dating in the La Ronge Domain; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

K-Ar dating is being undertaken to complement Rb-Sr, Sm-Nd and U-Pb studies already underway in the Precambrian Shield of Saskatchewan. The purpose of this dating is to ascertain the time of gold mineralizing events, the last heating episode in certain elements of the Shield and the time of uplift. The first area to be sampled is the Central Metavolcanic Belt (CMB) of the La Ronge Domain, chosen to tie in with the active mapping and other studies in progress there.

Sampling of selected areas in the CMB was initiated in 1986 in cooperation with the mapping parties of C.T. Harper and D.J. Thomas, and continued in 1987 with D.J. Thomas. Sampling in 1986 was also done in conjunction with K. Bell of Carleton University and R. Macdonald of Saskatchewan Energy and Mines. In both years, choice of units for sampling for K-Ar analyses was carried out in close consultation with the field geologists.

Due to an unforeseen delay during transport of the samples, the K-Ar dates for 1986 are still unavailable at this time. A list of the samples collected in both years is given below.

1986 Collection

SA 86-1 Star Lake Pluton: Quartz monzonite phase from barren country rock at the Star Lake Mine.

SA 86-2 Star Lake Pluton: Diorite phase, from high-grade gold ore zone at the Star Lake Mine.

SA 86-3 Star Lake Pluton: High-grade ore samples from the Star Lake Mine. These samples were taken from freshly mined material. Previous dating of the Star Lake Pluton includes a U-Pb date on zircon of 1848±14 Ma (Bickford et al., 1986) and a Rb-Sr isochron date of 1823±44 Ma, with an intercept of 0.7020 (Watters, 1986).

SA 86-4 Mafic lapilli tuff from Cockwill Lake: A hornblende porphyroblastic metavolcanic rock (Thomas, 1985).

SA 86-5 Tower Lake Intrusive: Diorites intruding metavolcanic rocks (Harper, 1985) and associated with the Tower East gold deposit.

SA 86-6 Upper Waddy Lake area, Komis Gold Deposit: A black metavolcanic rock containing disseminated pyrite which is surrounded by biotite (Harper, 1984).

SA 86-7 Mafic metavolcanic rock: Near Star Lake Mine, 7.6 km from gate along mine road, sample taken from mafic metavolcanic units which are country rock to the Star Lake Pluton (Thomas, 1984, 1986).

SA 86-8 Feldspar-phyric metavolcanic (dacite?): 6.6 km from gate along Star Lake Mine road (Thomas, 1984, 1986).

SA 86-9 Biotite- and hornblende-bearing metavolcanic rock: In shear zone 100 m north-northeast of sample 86-8. Hornblende on shear surfaces postdates the shearing (Thomas, 1984, 1986).

1987 Collection

The sample numbering is not consecutive because some samples were collected for Rb-Sr dating only. The geology of the following samples is discussed in Thomas (this volume) and other references as shown.

SK 87-1 Bartlett Lake Dyke Suite: A mafic dyke from northwestern corner of the westernmost island at north end of Bartlett Lake.

SK 87-2 Mafic dyke: From southeastern corner of same island as sample 87-1.

SK 87-3 Pegmatite dyke: From southeastern corner of the same island as sample 87-2.

SK 87-4 Bartlett Lake Intrusion: A granodiorite host to the dykes, collected on shore west of the same island as sample 87-1.

SK 87-6A Muscovite- and tourmaline-bearing pegmatite: Intrudes mafic metavolcanics on southeast shore of South Berg Lake, 10 km southwest of Missinipe.

SK 87-6B Biotite pegmatite: Collected just north of sample 6A.

[1]Department of Geology and Planetary Science, University of Pittsburg, Pittsburgh, Pennsylvania.
Project supported under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

SK 87-7 Cockwill Lake pyroclastic schist: A lapilli-blastic hornblende-bearing metavolcanic rock (Thomas, 1985).

SK 87-8A Star Lake Pluton: A coarse diorite phase from the Rod zone on the Jolu gold property at Mallard Lake.

SK 87-8B Star Lake Pluton: A fine phase of the same rock as sample 87-8A.

SK 87-9 Ore zone biotite in quartz veins: From freshly mined material in the ore dump from the 75 level of the Rod zone decline.

SK 87-10 Hornblende-actinolite-biotite-tourmaline(?) rock: From 75-9 level of the Rod Main zone.

SK 87-11 Bridgeman Lake Pluton: From lake shore exposure on the northern part of the southwest-trending bay of Bridgeman Lake. This porphyritic alkali granite or monzonite has sporadic blue quartz and is intrusive into Maclean Lake Belt rocks.

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Project 8704

U-Pb Zircon Geochronology Project: New Results and Interpretations

by M.E. Bickford[1], W.R. Van Schmus[1], K.D. Collerson[2] and R. Macdonald

Bickford, M.E., Van Schmus, W.R., Collerson, K.D. and R. Macdonald (1987): U-Pb zircon geochronology project: new results and interpretations; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

Funding for the U-Pb zircon geochronology study of the Trans-Hudson Orogen and Churchill Platform from the U.S. National Science Foundation expired in February this year, and is being bridged with a contract under the Canada-Saskatchewan Mineral Development Agreement 1984-89 until U.S. funds are renewed. This year our studies, based upon previously collected samples, have been as follows.

Churchill Platform

A paper by M.E. Bickford and K.D. Collerson, presented at the Geological Association of Canada meetings in Saskatoon in May, 1987 (Bickford and Collerson, 1987), provided data and interpretations from both the Keewatin and Cree Lake zones of the Churchill Platform. Last year (Bickford et al., 1986), we reported zircon age data for three samples from the Keewatin zone of the Churchill Platform. HUD-85-1 (Junction Granite) zircons indicate a Hudsonian age (1820±19 Ma), but the zircons have inherited xenocrystic cores having isotopic compositions suggestive of derivation from Archean source rocks. HUD-85-2 ("blue quartz" gneiss) and HUD-85-6 (large inclusion of gneiss in anorthosite) are both in granulite facies and have a mixed zircon population, including clear zircons that yield an age of about 2000 Ma, as well as dark corroded zircons yielding older ages, again suggestive of derivation from Archean rocks.

Here we report new data from two samples from the Mudjatik Domain, Cree Lake Zone. As will be seen, these samples appear to have experienced a similar history to those in the Keewatin Zone.

HUD-85-5 is a sample of charnockitic rock collected on a small island in Dipper Lake (approx. 55°58'N, 107°20'W). The sample yielded a uniform population of clear zircons that gave U-Pb analyses indicating an age of about 2000 Ma (Fig. 1).

HUD-85-6 is a sample of an upper amphibolite facies gneiss collected on the south shore of Dipper Lake (approx. 55°56'N, 107°18'W). This sample yielded a very complex zircon population with U-Pb analyses yielding an equally complex set of data points (Fig. 2). We have interpreted these data as indicating an age between 1889 and 2003 Ma (Fig. 2).

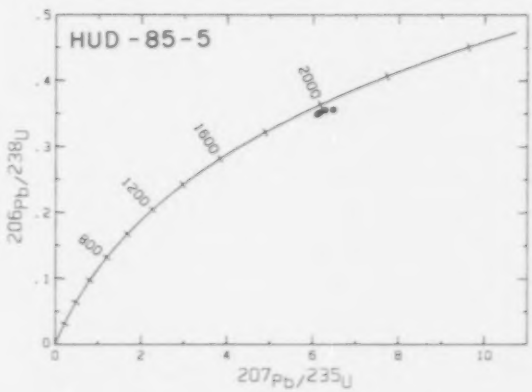

Figure 1 - Preliminary concordia diagram for zircon fractions from a charnockitic rock in the Mudjatik Domain, Cree Lake zone.

Samples from the Keewatin and western part of the Cree Lake zones show a common history. With the exception of the Junction Granite, they appear to be Archean rocks that experienced high-grade

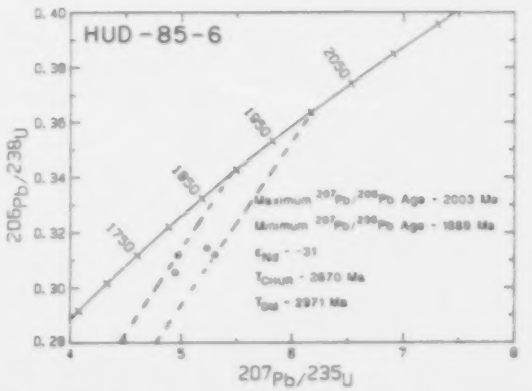

Figure 2 - Preliminary concordia diagram for zircon fractions from an upper amphibolite facies gneiss in the Mudjatik Domain, Cree Lake zone.

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[2]Department of Earth Sciences, University of California, Santa Cruz, California.
Funded partly by the U.S. National Science Foundation and the Canada-Saskatchewan Mineral Development Agreement 1984-89.

metamorphism about 2000 Ma, which evidently produced a growth of metamorphic zircons. These are the only zircons recovered from HUD-85-5. In the other samples, residual corroded zircons are variably overgrown with younger rims and are rather strongly discordant, indicating probable Archean ages. As indicated in Figs. 1 and 2, Sm-Nd model ages ("mantle separation ages") determined by K.D. Collerson for HUD-85-5 and HUD-85-6 are Archean, as also are Sm-Nd model ages for HUD-85-1 and HUD-85-8 (not shown here). Since the Junction Granite yields a Hudsonian age, contains relict xenocrystic zircons and has an Archean mantle separation age, we believe that it is the product of anatexis during Hudsonian orogeny (Figs. 1 and 2).

These results indicate that the thermotectonic history of the Churchill Platform is complex indeed. The 2000 Ma event is also seen in the ages of rocks from the Uranium City area (Bell and Bikerman, 1985; Van Schmus et al., 1987), and was clearly a major event in the evolution of the Churchill Platform. Bickford and Collerson (1987) suggested that this event may correspond with the assembly of the Churchill Platform. The 1820 Ma age of the Junction Granite indicates that Hudsonian thermotectonism was extremely widespread, extending far to the west of the Needle Falls Shear Zone which is the boundary of obviously orogenic rocks.

Peter Lake Domain and Cree Lake Zone

In last year's report (Bickford et al., 1986), we also reported the ages of samples collected in the Peter Lake Domain. Of these, HUD-85-25A and HUD-85-25B, respectively tonalitic and granitic gneisses collected along the shore of Reindeer Lake southwest of Crane Island, yielded zircon ages of about 2500 Ma, but both have Sm-Nd model ages of 2700 to 2800 Ma. HUD-85-25E, a cross-cutting dyke, yielded a zircon age of 1860±5 Ma, but has a Sm-Nd model age of 2385 Ma.

This year we report a refined zircon age from HUD-85-24 and a new age from HUD-85-19.

HUD-85-24 - The data available last year for this sample of gabbro pegmatite included two moderately discordant fractions and one strongly discordant fraction. Regression of these yielded 1865±10 Ma, the age reported last year. Another moderately discordant fraction was analyzed this year and found to be essentially colinear with the previously analyzed moderately discordant fractions, in distinction to the strongly discordant fraction. Regression of the three colinear fractions yields an age of 1908±27 Ma, with a lower intercept of 1001±120 Ma (Fig. 3). We consider this a much better estimate of the true age of the sample.

HUD-85-19 - This sample of granitic gneiss from the Johnson River Inlier, Cree Lake zone was

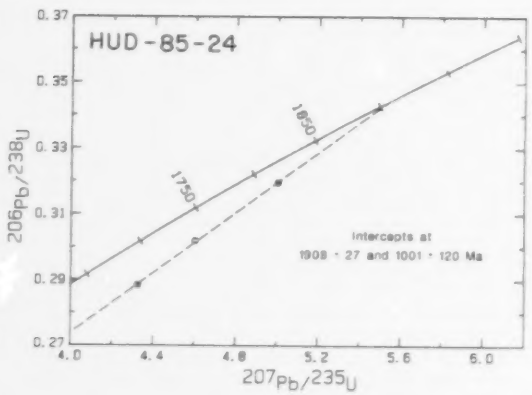

Figure 3 - Preliminary concordia diagram for zircon fractions from a gabbro pegmatite in the Peter Lake Domain.

collected from a small island in Compulsion Bay, Wollaston Lake. Six zircon fractions indicate an age of 2186±46 Ma (Fig. 4). The samples also yielded a Sm-Nd model age of 2851 Ma.

These results may indicate that rocks in the Peter Lake Domain have primary ages of 2700 to 2800 Ma but were remobilized about 2600 Ma. An alternate interpretation is that the rocks were separated from the mantle and crystallized about 2600 Ma, and that the Sm-Nd model ages are somewhat in error because the depleted mantle model used in the calculations does not apply to their petrogenesis.

The 1908±27 Ma age for the gabbro pegmatite indicates an earliest Hudsonian event, perhaps related to initial rifting.

The 1860±5 Ma age obtained last year for the cross-cutting granitic dyke is clearly Hudsonian and

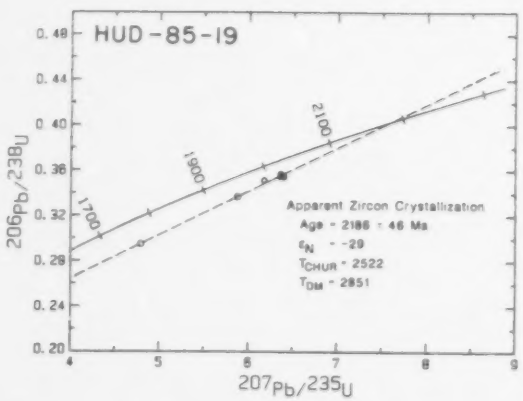

Figure 4 - Preliminary concordia diagram for zircon fractions from a granitic gneiss in the Johnson River Inlier, Cree Lake zone.

indicates either Hudsonian remelting of Peter Lake rocks or intrusion by apophyses of the Wathaman Batholith. The significance of the Sm-Nd model age of 2385 Ma for this sample is not clear at present.

Significantly, rocks of the Peter Lake Domain do not appear to have experienced the 2000 Ma granulite facies metamorphism seen to the west. Bickford and Collerson (1987) suggested that the Peter Lake Domain is exotic and was accreted to the Churchill Platform prior to or during Trans-Hudson orogenesis.

The 2189±46 Ma age for the granitic gneiss of the Johnson River Inlier is also intriguing, for the only age reported earlier for this unit is about 2500 Ma (Ray and Wanless, 1980). The data suggest that this gneiss is an anatectic granitoid derived by melting of Archean crust about 2200 Ma. This event may represent an early phase of the widespread 2000 Ma thermotectonism seen in rocks of the Keewatin and Cree Lake zones to the west.

Hanson Lake Block

One of our goals during sample collecting in 1986 was to clarify age relationships in the Hanson Lake Block. Coleman (1970) had reported a Rb-Sr isochron age of 2375±30 Ma for a collection of rocks in the Hanson Lake area. A zircon age of 1881±6 Ma for metarhyolite (HUD-83-7 collected from a mapped unit represented on Coleman's isochron was subsequently reported by Van Schmus et al. (1987). As a result of this date, we collected samples from several of Coleman's collecting sites during the summer of 1986. One of these has been determined as follows:

HUD-86-15, a granodiorite exposed on the shore of Bertram Bay of Hanson Lake, should be the same rock as Coleman's sample 55. Our sample yielded abundant zircons and four fractions which indicate an age of 1844±12 Ma (Fig. 5). The age of this granodiorite is quite similar to most of the plutons we have dated elsewhere in the Trans-Hudson Orogen in Saskatchewan.

Possible explanations of the striking discrepancy between our result and Coleman's are as follows: Coleman's isochron was defined by analytical data from nine samples, (four granites and five volcanic rocks). If the granite samples were collected from several different bodies, or a single body with variable initial $^{87}Sr/^{86}Sr$ ratio, the apparently isochronous relationship may be fortuitous. We have calculated that if Coleman's analytical data are correct, his sample 55 would need to have an initial $^{87}Sr/^{86}Sr$ of 0.7255 in order to yield an age of 1844 Ma. This is a high initial Sr isotopic ratio, but not unreasonably so if the rock was derived by anatexis of Archean crust. Alternatively, a systematic error in $^{87}Rb/^{86}Sr$ ratios, perhaps caused by difficulties in either Sr or Rb spiking, could have produced this result.

HUD-86-19 is a sample of the Jan Lake Granite. This posttectonic aplitic to pegmatitic granitic suite occurs in sheets and dykes in the Hanson Lake Block. We anticipated that the Jan Lake Granite would be significantly younger than most Hudsonian rocks in this area and that its age would place a lower limit upon the time of deformation. Fig. 6 shows the results of analyses of four fractions of zircons from the suite. The indicated age is 1773±9 Ma, the lowest age yet determined by the U-Pb zircon method in the Trans-Hudson orogen.

J. Chiarenzelli, a doctoral student at the University of Kansas, has produced a zircon age of about 1800 Ma from late pegmatites in the Nistowiak Lake area, Glennie Terrain, and a Pb-Pb age of about 1768 Ma from monazite in a late undeformed granitoid in the same area. It seems clear that deformation, and presumably terminal collision, was completed in this part of the Trans-Hudson Orogen by about 1770 Ma.

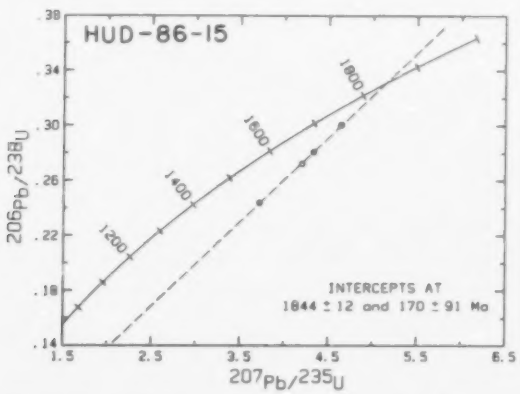

Figure 5 - Preliminary concordia diagram for zircon fractions from a grandiorite, Hanson Lake Block.

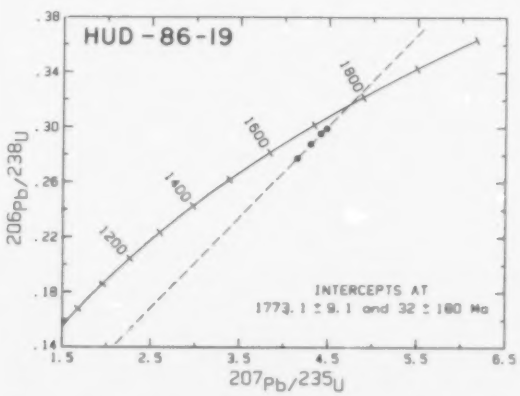

Figure 6 - Preliminary concordia diagram for zircon fractions from the Jan Lake Granite, Hanson Lake Block.

Greater Beaverlodge Area

HUD-84-311 is a sample from the Stephens Lake Granite in the Beaverlodge area. The sample was collected from that part of the granite where the regional metamorphic grade is amphibolite facies. Several zircon fractions were analyzed, and a suite of four untreated fractions (solid circles, Fig. 7) yielded an apparent age of ca. 2410 Ma. This granite was anticipated to be approximately the same age as the Mackintosh Bay Granite and the Athona Mine Granite nearby to the south, which have been previously dated at 2356 Ma and 2327 Ma, respectively by the U/Pb zircon method (Persons, 1987).

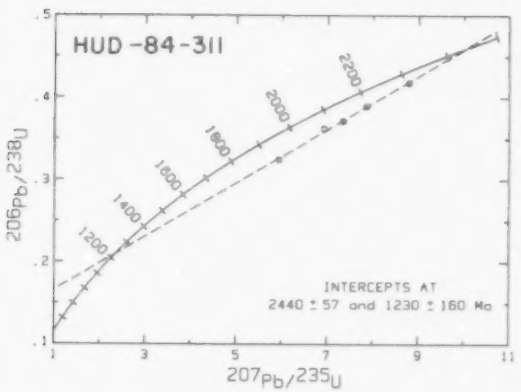

Figure 7 - Preliminary concordia diagram for zircon fractions from the Stephens Lake Granite, Beaverlodge area.

The apparent age of 2410 Ma for the Stephens Lake Granite is older than anticipated. In order to examine the possibility of the existence of older cores, one fraction was air-abraded. That fraction has a distinctly older Pb-Pb age and, if it is regressed with the untreated fractions, the resulting chord has a significantly older upper intercept of 2440 Ma. We conclude that the apparent age of 2410 Ma from the untreated fractions may be influenced by older cores, and that the true age could be significantly younger.

Checks with air-abraded fractions were made for the Mackintosh Bay and Athona Mine granites (Persons, 1987), and similar features were not noted. We conclude that the age of the Stephens Lake Granite is probably between 2400 and 2340 Ma. Further analyses are planned to refine this interpretation.

Acknowledgments

The work presented here has been supported by Grant EAR 8313167 from the National Science Foundation of the United States Government and by a contract awarded under the Canada-Saskatchewan Mineral Development Agreement 1984-89 administered by Saskatchewan Energy and Mines. We are grateful for stimulating exchanges with K. Bell, Carleton University, Ottawa; J.F. Lewry, University of Regina; and R. Macdonald and J.G. Pearson, Saskatchewan Energy and Mines.

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Project 8705

Mineralized Core Collection

by A.J. Gracie

Gracie, A. J. (1987): Mineralized core collection; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

The Mineralized Core Collection has been previously described (Gracie, 1984, 1985, 1986) and an updated index to the collection released this year as a data file (Gracie et al., 1987). The index identifies the location of all core from drill holes by longitude and latitude and on 1:250,000 scale maps, and gives full particulars of each hole (company, mineral dispositions, exploration commodity, year, hole number, core size, hole bearing and inclination, length of sample, reference to other exploration data and storage location).

The core is housed in the Precambrian Geological Laboratory in La Ronge. Contributions to the Mineralized Core Collection totalled some 5497m in 1987 (Table 1) and were made up largely of cores, from the region surrounding Flin Flon, which had been previously collected and stored in Creighton. Ninety-seven persons examined core from the collection and two persons resampled core from two separate properties. The mineralized core collection is augmented by an extensive collection of rock samples from mineral prospects in northern Saskatchewan.

Project funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

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Table 1 - Core Acquisitions, September 1, 1986 to August 31, 1987

Company or Joint Venture Operator (Commodity)	NTS Area	No. of Holes	Core Size	Property/Deposit Location by Lake	Meterage (m)
Eldor Mines Ltd. (U)	64-L-5-SE	3	BQ	ML 5358 Collins B Zone	293 m
Flin Flon Mines Ltd. (Au)	63-K-12-NW	2	NQ	ML 5106 Cor showing	52.5 m
Flin Flon Mines Ltd. (Au)	63-K-12-NW	12	NQ, BQ	ML 5112 Rio zone, Bootleg Lake	860 m
Glitter Gold Mines Ltd. (Au)	63-M-11-SW	2	BQ	CBS 7591	101 m
Granges Exploration Ltd. (Cu,Zn)	63-L-11-SE	2[1]	BQ	CBS 7097 Bigstone Lake	189 m
Kenton Natural Resources Corp. (Au)	63-L-9-NW	4	NQ	S98062 Amisk Lake	320 m
Key Lake Mining Corp. (U)	74-H-4-NE	13	BQ NQ	ML 5205 Gaertner orebody	697 m
Hudson Bay Exploration and Development Ltd. (Cu)	63-L-9-NE Unconcentrated Concentrated	1 5	Ext Ext	ML 4559 Birch Lake	651 m
(Cu)	63-L-16-NE	1	Ext	ML 5171 Otonadah Lake	11 m

[1]one hole incomplete

Table 1 - Core Acquisitions, September 1, 1986 to August 31, 1987 (Cont'd)

Company or Joint Venture Operator (Commodity)	NTS Area	No. of Holes	Core Size	Property/Deposit Location by Lake	Meterage (m)
Hudson Bay Exploration and Development Ltd. (Cu)	63-L-9-NE	2	Ext	ML 5113 Echo Lake	51 m
(Cu)	63-L-10-NE	1	Ext	ML 5177 Wakisew Lake	12 m
(Cu)	63-K-12-SW			ML 4814	
	Unconcentrated	2	Ext	McNally Lake	413 m
	Concentrated	1	Ext	Coronation Mine	33 m
(Zn)	63-L-16-SW	1	Ext	CBS 904 Abbott Lake	23 m
(Au)	63-K-12-NW	1	NQ	S90616 Bomber Lake	40 m
(Cu)	63-L-9-SE	1	AXT	S87108 Stitt Lake	64 m
Saskatchewan Mining Development Corp. (Au)	63-L-9-NE	2	NQ	ML 5262 Wolverine Lake	146 m
(Cu)	63-L-9-NW	3	BQ	ML 5274 Gull Island	126 m
(Au)	73-P-7-SW	1	NQ	ML 5426 Sulphide Lake	81 m
(Ni,Cu,Zn,Pb,Au)	63-L-2-NW	1	NQ	CBS 8792 Pine Bluff	216 m
(Au)	63-L-9-NW	4	BQ	S95827/8 Waverley Island	138 m
Stall Lake Mines Ltd. (Cu Zn)	63-M-1-SE	1	Axt	ML 5018 Schotts Lake	132 m
Straus Exploration Inc. (Cu)	63-M-15-NE	35	Axt	ML 5269 Mokoman Lake	768 m
Wapa Minerals Ltd. (Au)	63-N-4-SW	1	NQ	ML 5393 Mari Lake	79 m

Rare Earth Elements and their Occurrence in Northern Saskatchewan

by C.T. Harper

Harper, C.T. (1987): Rare earth elements and their occurrence in northern Saskatchewan; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

The steadily growing demand for rare earth elements (REE) and yttrium (Y) in petroleum cracking catalysts, the electronics industry, and the manufacture of super conductors, permanent magnets, ceramics, glass and metal alloys indicates that these elements are worthy of exploration attention. The purpose of this paper is firstly to illustrate the character, variety and distribution of REE occurrences in general, and particularly in northern Saskatchewan, and secondly to fulfill a demand from the mineral industry for information on these REE occurrences.

The Rare Earth Elements

Rare earth elements, or the lanthanide series, constitute a group of 15 elements (16 including yttrium) beginning with lanthanum (atomic no. 57) and ending with lutecium (atomic no. 71) (Table 1). Although generally more abundant than elements such as gold, silver and uranium (Mason, 1966), REE rarely form distinct minerals in nature, occurring instead in trace amounts in over 250 minerals, of which 54 are designated as lanthanide minerals (Valasov, 1966).

Despite their relative abundance, there are only three major ore minerals for REE and Y: monazite, bastnasite and xenotime. Monazite, a REE-Y-Th phosphate, contains up to 70 percent REO (rare earth oxide), 7 percent ThO and 2 percent Y_2O_3. Bastnasite is a rare earth fluorocarbonate which contains up to 75 percent REO and minor Y_2O_3. Xenotime is a yttrium phosphate, which contains up to 60 percent Y_2O_3 and is more enriched in the 'heavy' REE, dysprosium (Dy, atomic no. 66) to lutecium (Anstett, 1986). Both monazite and bastnasite are 'light' REE enriched.

Minor ore minerals include apatite, allanite, brockite, crandalite, euxenite and loparite.

Until recently, monazite was the principal source of REE. It occurs in many geological environments, being most prominent in felsic igneous rocks such as granites and pegmatites. Most monazite is extracted from heavy mineral beach sands as a byproduct of sands mined for ilmenite, rutile, cassiterite, zircon or gold. The principal mining areas are along the coasts of Australia, Brazil, India, South Africa and the United States.

Xenotime generally occurs in the same environments as monazite. Like monazite, it is a byproduct of placer mining, in particular the tin placers of Malaysia and China (Anstett, 1986).

Table 1 - Rare Earth Element Abundance in Chondrites, the Crust and Some Common Rocks. Values are in ppm.

Atomic No.	Element	Symbol	Average Chondrites[1]	Average Crust[2]	Average Granites[2]	Average Shales[2]	Average Basalts[2]
57	Lanthanum	La	.30 ± .06	35	55	40	10
58	Cerium	Ce	.84 ± .18	70	90	70	30
59	Praseodymium	Pr	.12 ± .02	8	10	9	4
60	Neodymium	Nd	.58 ± .13	30	35	30	20
61	Promethium	Pm					
62	Samarium	Sm	.21 ± .04	7	9	7	05
63	Europium	Eu	.074 ± .015	1.2	1.0	1.4	1.5
64	Gadolinium	Gd	.32 ± .07	7	8	6	6
65	Terbium	Tb	.049 ± .010	1	1.5	1	0.8
66	Dysprosium	Dy		6	6.5	5	4
67	Holmium	Ho	.073 ± .014	1.5	2	1.5	1
68	Erbium	Er	.21 ± .04	3.5	4.5	3.5	3
69	Thulium	Tm	.033 ± .007	0.5	0.06	0.06	.05
70	Ytterbium	Yb	.17 ± .03	3.5	4.0	3.5	2.5
71	Lutetium	Lu	.031 ± .005	0.6	0.7	0.6	.05

[1]from Haskin et al. (1968)
[2]from Krauskopf (1979)

Bastnasite occurs in veins and as disseminations in carbonatite intrusions (e.g., Mountain Pass, California); quartz veins cutting micaceous schist and quartzite (Burundi); epithermal fluorite veins and breccia fillings in Permian sandstones (New Mexico); and associated with iron ore minerals (China). Bastnasite has now replaced monazite as the principal source of REE. The Mountain Pass deposit, which contains reserves of 3.6 million tons, produces 50 percent of the world's annual REO production (Anstett, 1986). The Chinese iron deposits may contain as much as 36 million tons REO (ibid.), but these deposits have yet to be developed.

In Canada, REE have been produced as a byproduct of uranium mining in the Elliot Lake region (Anstett,1986). Other Canadian reserves of REE and yttrium include Highwood Resources Ltd.'s beryllium - yttrium - rare earths - niobium deposit at Thor Lake in the Northwest Territories (James, 1986) and a columbium - fluorite - zirconium - beryllium - Y-rich gadolinite deposit near Strange Lake in northeastern Quebec (Hedrick, 1985; Anstett, 1986). A production decision is expected for the Thor Lake deposit by the end of 1987.

Saskatchewan Rare Earth and Yttrium Occurrences

There are more than 40 reported REE-bearing mineral occurrences in northern Saskatchewan (Fig. 1), the majority of which occur in high-grade gneiss terrains surrounding the Athabasca Basin. They can be subdivided into the following five types: 1) pegmatite-granite association; 2) metadetrital; 3) allanite veins; 4) detrital heavy mineral sands in the Athabasca Group; and 5) diagenetic-hydrothermal associated with unconformity-type uranium deposits.

Pegmatite-Granite Association

Most occurrences in Saskatchewan belong to the pegmatite-granite type; the majority are believed to have formed by anatectic processes. They consist predominantly of monazite with rare or minor xenotime associated with biotite-rich segregations in pegmatites or restites of the enclosing high-grade gneisses. Allanite, apatite, zircon and uraninite may also be associated with this type of occurrence. Available assays typically range from 0.008 to 2.0 percent total REO, but south of Alces Lake in the Beaverlodge region, two monazite-bearing pegmatite occurrences contain up to 16 percent REO (Robinson, 1955; Assessment File 74N09-0020, Saskatchewan Energy and Mines, Regina).

Two other significant occurrences include Kulyk Lake and Jahala, both of which were originally discovered as uranium prospects. At Kulyk Lake, located 1 km west of Middle Foster Lake, massive monazite occurs in pegmatitic, graphic and aplitic granite dykes which intrude high-grade gneisses of the Wollaston Domain (Mawdsley, 1957; Watkinson and Mainwaring, 1976; Assessment File 74A12-0005, Saskatchewan Energy and Mines, Regina). There is mineralogical zoning from Fe-Ti oxides to monazite to minor concentrations of apatite in a zone less than 5 cm thick and approximately 15 m long.

The Jahala prospect, located 8 km east of Hunter Bay, Lac La Ronge, occurs in a zoned pegmatite sill intruding amphibolitic metasediments (Mawdsley, 1954; Ford, 1955; Forsythe, 1981; Sabina, 1987). Uraninite is accompanied in this occurrence by monazite, allanite, apatite, zircon and xenotime. Dark brown monazite crystals, up to 1 cm long, are associated with massive biotite selvages of the border zone (Ford, 1955) and are also reported to occur in the intermediate phase of the pegmatite (Mawdsley, 1954). Estimates of the volume of

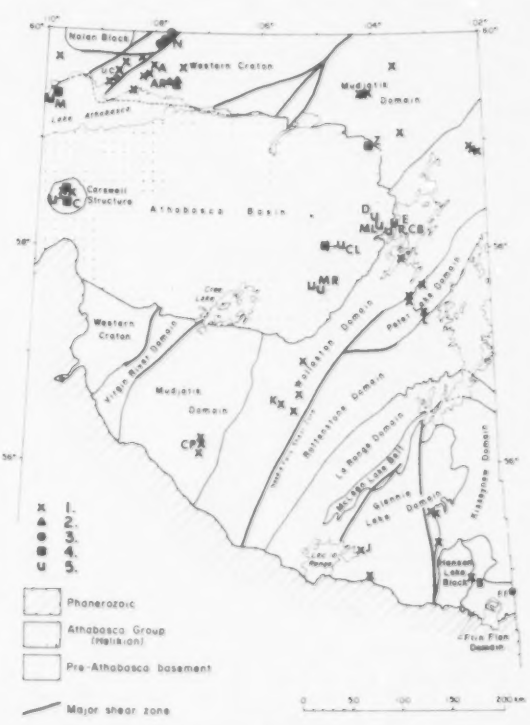

Figure 1 - Distribution of reported rare earth element and yttrium occurrences in northern Saskatchewan. Occurrence types: 1, pegmatite-granite association; 2, metadetrital; 3, allanite veins; 4, heavy mineral layers in the Athabasca Group; and 5, diagenetic-hydrothermal type associated with unconformity uranium deposits. Place names mentioned in text include: A, Alces Lake; AR, Archie Lake; B, Birch Portage; C, Cluff Lake; CB, Collins Bay; CL, Cigar Lake; CP, Cup Lake; D, Dawn Lake; E, Eagle Point; F.F., Flin Flon; J, Jahala; K, Kulyk Lake; L, Lyle Lake; M, Maurice Bay; ML, McLean Lake; MR, McArthur River; N, Wisikkatch-Hoidas Lakes; R, Rabbit Lake; U.C., Uranium City; and Z, Zoo Bay.

REE-bearing minerals present and geochemical analyses are not available for the Jahala or Kulyk Lake occurrences.

Several occurrences with interesting mineralogical associations include:

1) a monazite-bearing syenitic pegmatite closely associated with the Lyle Lake nepheline syenite (MacDougall, this volume);

2) beryliferous pegmatites in the Birch Portage area, 50 km west of Flin Flon, some of which contain accessary monazite (Radcliffe and Campbell, 1965; Pyke, 1966; Sabina, 1987); and

3) a group of radioactive pegmatites in the Cup Lake area which generally contain less uranium than thorium; uraninite, molybdenite, fluorite and allanite have been identified, as well as niobium-tantalum values (Munday, 1977; Thomas, 1983).

REE occurrences associated with pegmatites are typically found as a result of uranium exploration due to the radioactivity of thorium in monazite and/or allanite. As thorium is commonly more abundant than uranium in these occurrences, they have attracted little attention, and consequently are rarely if ever checked for REE.

Metadetrital

An ilmenite-monazite occurrence in Archean granulite facies metasedimentary gneisses at Archie Lake, 30 km east-southeast of Uranium City (Fig. 1), is believed to represent a metamorphosed heavy mineral accumulation (Harper, 1986, 1987). Ilmenite, monazite and trace amounts of zircon and gold occur in layers 0.1 to 10 cm thick within a 5 to 6 m thick stratabound zone that has been traced over a strike length of 600 m. Radioactive anomalies along strike from the main occurrence suggest the possibility of further extensions to the zone or additional 'heavy mineral' lenses. Assays of material from the main zone range from 0.1 to 15.7 percent total REO (Assessment Files 74O5-0038, -0053, and -0059, Saskatchewan Energy and Mines, Regina) and locally TiO_2 exceeds 17.0 percent. Several other ilmenite-monazite occurrences exist in the surrounding area (Harper, 1983b, 1986). Undoubtedly other meta-detrital occurrences exist elsewhere in the Saskatchewan Shield.

Allanite Veins

A unique group of allanite-apatite veins occur in the Nisikkatch - Hoidas Lakes area, 40 km northeast of Uranium City (Fig. 1). The veins, which cut granulite and retrogressed granulite facies gneisses, are found in a zone up to 10 km long. Mineralogical zoning is common and includes calcite, barite, hyalophane (Ba-feldspar), amphibole and pyroxene (Hogarth, 1957). Grab samples have given assays of up to 12 percent total REO (Assessment File 74O13-0001, Saskatchewan Energy and Mines, Regina).

Heavy Mineral Layers in the Athabasca Group

Athabasca Group sandstones and conglomerates contain heavy mineral layers, especially in the dominantly conglomeratic basal section. Detrital zircon, monazite and xenotime have been identified in some places (e.g., Maurice Bay (Harper, 1978, in prep.); Cluff Lake (Pagel, pers. comm.); Zoo Bay (No. 1149, Saskatchewan Mineral Deposits Index, Regina)); however, these layers remain essentially untested for REE-bearing paleoplacer deposits.

Diagenetic-Hydrothermal Type

The association of REE and Y with the Athabasca Basin unconformity uranium deposits is only beginning to be appreciated. For example, strongly altered clay-enriched Athabasca Group sandstones above the McClean Lake uranium deposits contain up to 10 percent Y, present in masses of xenotime and goyasite in the clay (Wallis et al, 1985). Xenotime and goyasite are also associated with uranium mineralization in the McArthur River area, located northeast of Key Lake (Hubregtse and Sopuck, 1987). Yttrium geochemical anomalies, ranging from three to seven times background, occur above the Cigar Lake and Dawn Lake uranium deposits (Clark, 1987), and elevated Y concentrations exist at the Rabbit Lake, Collins Bay and Eagle Point deposits (Ruzicka, 1986). Locally at Cluff Lake and Maurice Bay, REE are progressively enriched along with uranium (Harper, 1983a and unpublished data). The association of these occurrences with Athabasca Basin unconformity uranium deposits suggests a potential for "unconformity-type" diagenetic-hydrothermal Y and REE ore.

Conclusion

Rare earth elements occur in diverse geological settings, any of which could contain ore-grade material. The growing awareness of the important industrial uses of REE and Y, coupled with a steadily increasing demand, will undoubtedly lead to increased exploration attention. A variety of REE and Y exploration targets exist in northern Saskatchewan, with a good potential for the discovery of economic concentrations of these elements.

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Update on the Precambrian Geology and Domainal Classification of Northern Saskatchewan

by R. Macdonald

Macdonald, R. (1987): Update on the Precambrian geology and domainal classification of northern Saskatchewan; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

In recent years there has been much progress in the development of ideas on the evolution of our understanding of the Precambrian geology of northern Saskatchewan. As part of this evolution, various authors have introduced a number of new stratigraphic, rock unit and lithostructural domain terms into the literature.

Responding to the need for coordination and some guidance in this area of terminology, the Saskatchewan Geological Survey has recently started a microcomputer-based Precambrian Lexicon. This lexicon lists the sources of rock unit and domain names, and is expected eventually to provide recommendations on their usage. The intent of the present report and map figures is to provide a topical summary of the Precambrian geology of northern Saskatchewan from the perspective of this terminology.

General

The Precambrian rocks of northern Saskatchewan now have a dated history which commenced ca. 3070-3014 Ma ago and continued through tectono-metamorphic episodes until Neo-Helikian times (ca. 1450-1350 Ma) at which time the post-metamorphic sedimentary Athabasca Basin was formed.

Following the lead by Lewry and Sibbald (1977), the pre-Athabasca rocks have been divided into a number of lithostructural domains (see also Macdonald and Broughton, 1980). Fig. 1 summarizes the more recent modifications of this domainal classification. These domains have been grouped into three broad regions, namely the "Western Craton", the Cree Lake Zone and the Reindeer Zone. These in general terms represent distinctive remnant facets of a sector of the Lower Proterozoic Trans-Hudson Orogen.

1. The "Western Craton": Western Foreland to the Trans-Hudson Orogen

The Western Craton - as originally defined by Lewry and Sibbald (1977) - is that part of the Shield lying west of the Virgin River and Black Lake Shear Zones. In regional terms it is part of the Keewatin Zone (Hoffman, 1987) which underlies neighbouring parts of the Northwest Territories, and the Virgin River and Black Lake Shear Zones are part of the Snowbird Line. The craton is exposed north and south of the Athabasca Basin and in the window of the circular Carswell Structure. Limited information is also available from drill core under the Athabasca Group. The craton may be described under the heading of a southern and northern region.

1A. Southern Region:

The terrain south of the Athabasca Basin is almost entirely underlain by rocks of the **Western Granulite Domain** (Lewry and Sibbald, 1977) which comprise a variety of felsic (charnockitic to enderbitic) through to mafic (noritic) rocks with granulite or retrogressed granulite facies mineral assemblages characterized by blue quartz. Other rock types include pelitic gneisses and garnetiferous felsic gneisses derived from greywacke assemblages. Preliminary U-Pb dating indicates a minimum age of ca. 2290 Ma (Bickford et al., 1986).

The Western Granulite Domain also includes the **Clearwater Anorthosite.** Layered mafic plutons in the craton may be associated with these anorthosites (Collerson and Lewry, 1985). Preliminary U/Pb zircon dating of the anorthosite gives an emplacement age of ca. 2000 Ma (Bickford et al., 1986).

The southwestern margin of the domain is progressively more sheared towards the bounding **Virgin River Shear Zone.** In places along this margin there are swarms of late mafic dykes and sills (Wallis, 1970). The poorly exposed **Firebag Domain** (Lewry and Sibbald, 1977) to the west features similar lithological assemblages to those of the Western Granulite Domain.

The **Clearwater Domain**, which lies between the Western Granulite and Firebag domains, comprises granitoid rocks of which the **Clearwater Granite** is the most prominent. Wilson (1986) has identified a similar, but separate granitoid terrain (the **Wylie Lake Granitoid**) under the Alberta portion of the Athabasca Basin.

1B. Northern Region:

The Greater Beaverlodge area centred around Uranium City has been intensely studied on account of gold and uranium interests since World War II, and is probably a key to an understanding of neighbouring terrains. A number of domains have

been recently proposed for the northern region (Gilboy, 1981a; Macdonald, 1983a), refining the earlier subdivisions of Beck (1969) (Fig. 2).

The region has been subdivided into several cratonic blocks made up predominantly of Archean rocks which are generally bounded by mylonitic shear zones. Intervening terrains generally contain reworked Archean and/or Lower Proterozoic rocks. The Archean rocks are commonly similar to those of the Western Granulite Domain, and mineral assemblages are also generally typomorphic of

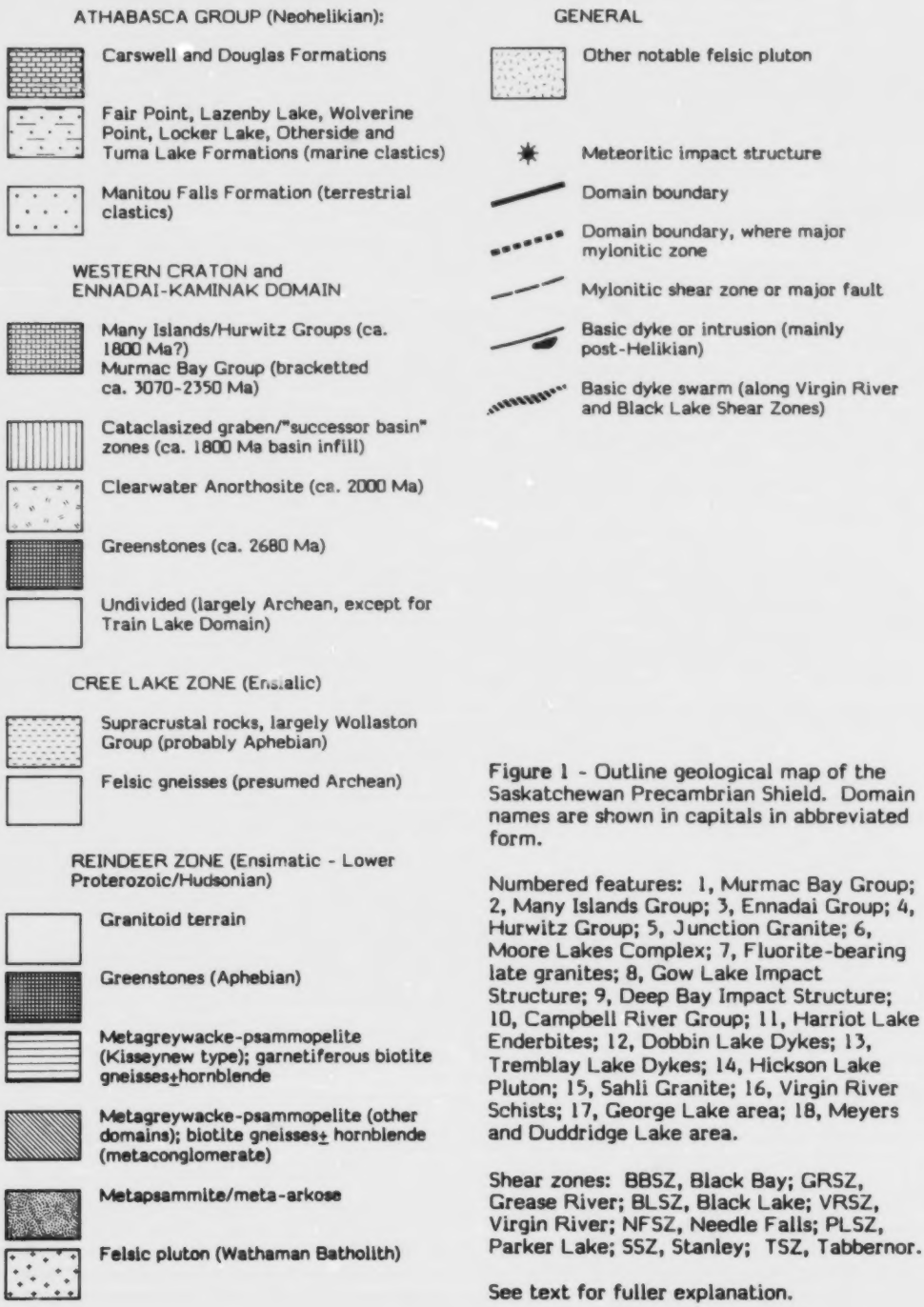

ATHABASCA GROUP (Neohelikian):
Carswell and Douglas Formations
Fair Point, Lazenby Lake, Wolverine Point, Locker Lake, Otherside and Tuma Lake Formations (marine clastics)
Manitou Falls Formation (terrestrial clastics)
WESTERN CRATON and ENNADAI-KAMINAK DOMAIN
Many Islands/Hurwitz Groups (ca. 1800 Ma?)
Murmac Bay Group (bracketted ca. 3070-2350 Ma)
Cataclasized graben/"successor basin" zones (ca. 1800 Ma basin infill)
Clearwater Anorthosite (ca. 2000 Ma)
Greenstones (ca. 2680 Ma)
Undivided (largely Archean, except for Train Lake Domain)
CREE LAKE ZONE (Ensialic)
Supracrustal rocks, largely Wollaston Group (probably Aphebian)
Felsic gneisses (presumed Archean)
REINDEER ZONE (Ensimatic - Lower Proterozoic/Hudsonian)
Granitoid terrain
Greenstones (Aphebian)
Metagreywacke-psammopelite (Kisseynew type); garnetiferous biotite gneisses±hornblende
Metagreywacke-psammopelite (other domains); biotite gneisses± hornblende (metaconglomerate)
Metapsammite/meta-arkose
Felsic pluton (Wathaman Batholith)
GENERAL
Other notable felsic pluton
Meteoritic impact structure
Domain boundary
Domain boundary, where major mylonitic zone
Mylonitic shear zone or major fault
Basic dyke or intrusion (mainly post-Helikian)
Basic dyke swarm (along Virgin River and Black Lake Shear Zones)

Figure 1 - Outline geological map of the Saskatchewan Precambrian Shield. Domain names are shown in capitals in abbreviated form.

Numbered features: 1, Murmac Bay Group; 2, Many Islands Group; 3, Ennadai Group; 4, Hurwitz Group; 5, Junction Granite; 6, Moore Lakes Complex; 7, Fluorite-bearing late granites; 8, Gow Lake Impact Structure; 9, Deep Bay Impact Structure; 10, Campbell River Group; 11, Harriot Lake Enderbites; 12, Dobbin Lake Dykes; 13, Tremblay Lake Dykes; 14, Hickson Lake Pluton; 15, Sahli Granite; 16, Virgin River Schists; 17, George Lake area; 18, Meyers and Duddridge Lake area.

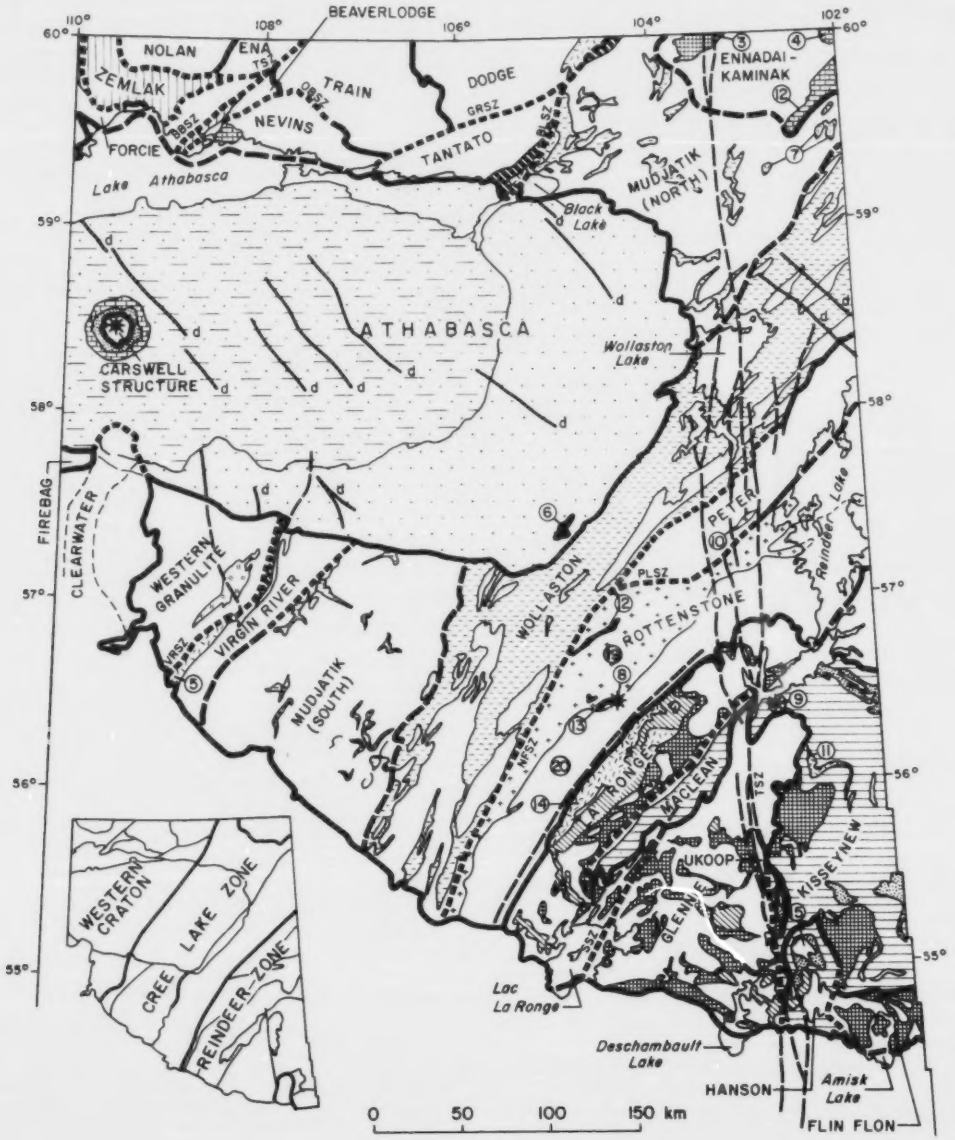
Shear zones: BBSZ, Black Bay; GRSZ, Grease River; BLSZ, Black Lake; VRSZ, Virgin River; NFSZ, Needle Falls; PLSZ, Parker Lake; SSZ, Stanley; TSZ, Tabbernor.

See text for fuller explanation.

retrogressed granulites facies. As pointed out by Sibbald (in press), and by Wallis (1970) for the southern region, these cratonic blocks are generally coincident on aeromagnetic maps with areas of relatively high magnetic relief.

Archean Blocks.- Although radiometric dates are lacking, the Dodge and Tantato Domains are presumed to be Archean and comprise a variety of partially retrograded granulite facies mafic to felsic rocks. Biotitic gneisses of possible sedimentary origin are more prominent in the Dodge Domain, but also occur in the garnetiferous felsic gneisses of the Pine Channel Assemblage in the Tantato Domain (Slimmon and Macdonald, this volume), where they are associated with thick bands of hypersthene-bearing mafic granulites, or so called 'norites'. The two domains are separated by the major Grease River Shear Zone. The Chipman Sill Swarm (Macdonald, 1980b) forms a zone up to 2 or 3 km wide along the Black Lake Shear Zone demarcating the southeastern boundary of these domains, in similar style to the southeastern margin of the Western Granulite Domain to the south.

The major part of the Nevins Lake Block comprises retrogressed assemblages: felsic gneisses, garnetiferous gneisses and mafic gneisses with rare



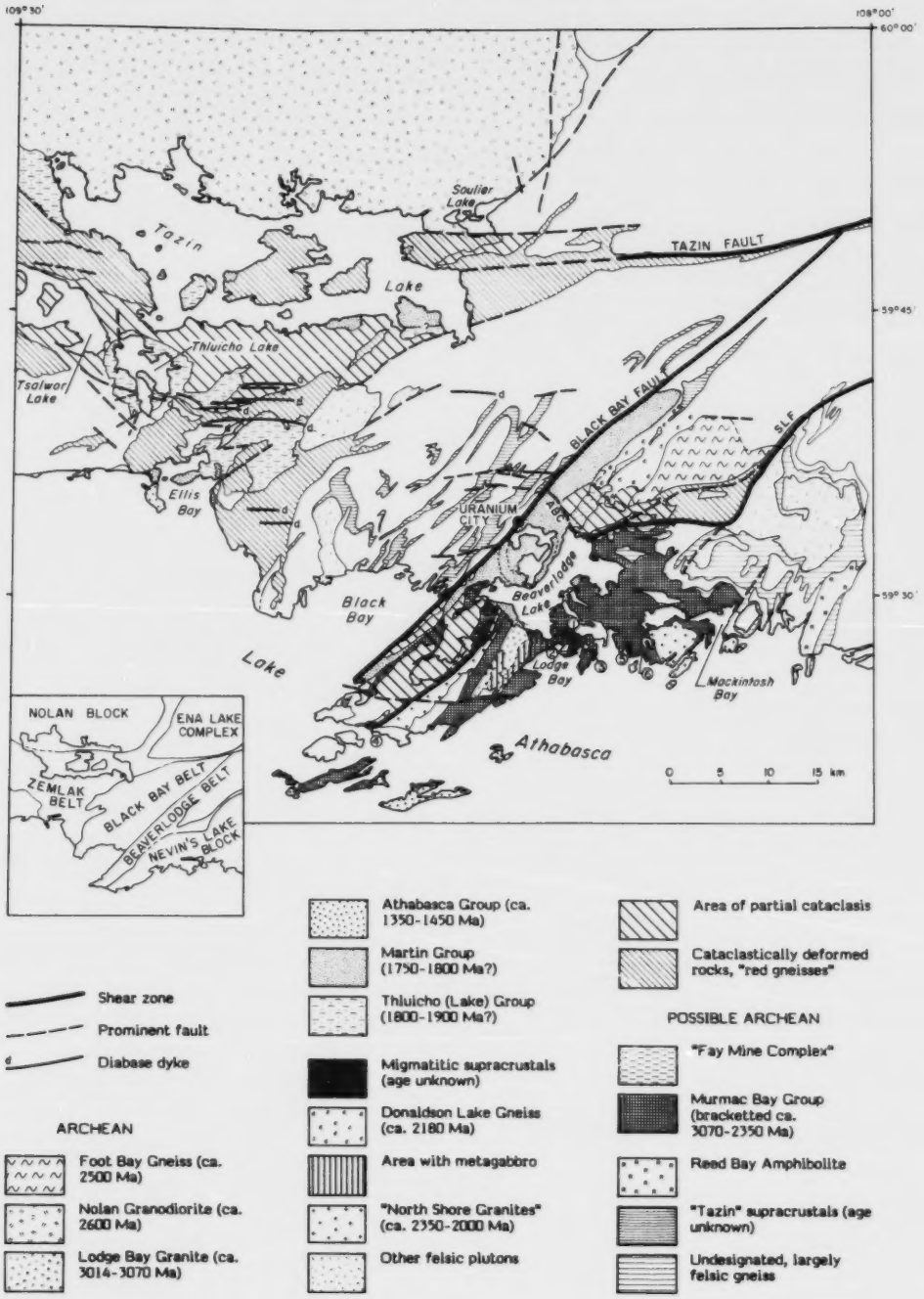


Figure 2 - Outline geology of the Greater Beaverlodge area and environs, northwestern Saskatchewan.

Numbered features: 1, Frontier Granite; 2, Box (Mine) Granite; 3, Athona Granite; 4, Gunnar Granite; 5, Nicholson Bay; 6, Fishhook Bay; 7, Site of Fay-Ace-Verna Mine (Eldorado); SLF, St. Louis Fault; ABC, ABC Fault.

See text for references to age dating.

quartzite (Harper, 1982b). Preliminary Rb-Sr dating indicates a minimum (probable metamorphic) age of 2631±130 Ma for a hypersthene gneiss, and a younger event at 2315±60 Ma for a garnetiferous felsic gneiss (Bell and Blenkinsop, 1984). To the west in the Greater Beaverlodge area, the metamorphic grade is lower and a supracrustal assemblage, the Murmac Bay Group, has been recognized. This miogeoclinal-type assemblage includes metaquartzite, garnet and biotite schist, metaconglomerate, dolomitic marble and pillowed metabasalt. A basement to this group has been identified recently in the form of the Lodge Bay Granite, and confirmed by U-Pb zircon ages of ca. 3070 to 3014 Ma (Van Schmus et al., 1986).

The Nolan Block comprises plutonic rocks with well defined U-Pb zircon ages of ca. 2581 to 2639 Ma (Van Schmus et al., 1986). This is the only terrain known in northern Saskatchewan to produce K-Ar ages in the range 2500 to 2300 Ma (Bell and Macdonald, 1982), indicating significant internal stability of the block since Archean times.

Remobilized Belts.- The remobilized belts exhibit a variety of features ranging from magmatic to cataclastic. The Greater Beaverlodge area has been affected by multiple reactivations since Lodge Bay Granite times some 3000 Ma ago (Table 1). In the Goldfields-Nicholson Bay area the Murmac Bay Group is intruded by the auriferous "North Shore Plutons". Determinations by the U-Pb zircon and Rb-Sr methods yield ages which group at ca. 2350, 2180 and 2000 Ma (Bell et al., 1986; Van Schmus et al., 1986). Some of these plutons appear to show classical metasomatic features. The 2000 Ma event is becoming recognized as an important regional feature generally in the Western Craton. The role of the Foot Bay Gneiss and the structurally overlying migmatitic Donaldson Lake Gneiss, with U-Pb zircon dates respectively of ca. 2500 and 2180 Ma, is imperfectly understood.

The Beaverlodge Cataclastic Belt lying immediately southeast of the Black Bay Fault is the remnant of an irregularly mylonitized and fractured graben into which post-metamorphic redbeds of the Martin

Table 1 - Outline geological chronology, Greater Beaverlodge area and environs, Saskatchewan

Approximate Dates (Ma)(1)	Nolan Block	Nevins Lake Block West	Nevins Lake Block East	Inter-block Terrain	Train Lake Domain	Mineralization
1350–1450			Athabasca Group			
1415				Gabbro sill		
1495				Basic dyke		
1750–1800?				Pegmatite		Initial pitchblende
1800–]				Martin Group		
]						
–1900?]				Thluicho Lake Group		Later syngenetic uraninite
1950±125*					Quartzofeldspathic gneiss	
1994±37*		North Shore Granites:				
2000		Box Granite Metasomatic (Box) phase				Gold?
2181±5*		Gunnar Granite				
2179±12*				Donaldson Lake Gneiss		
2200						Early syngenetic uraninite
2315±60			Garnet-feldspar gneiss			
2327±17*		Mackintosh Granite				
2356±14*		Athona Granite				
2350–2450	Cooling (K-Ar)					
2513±30*			Foot Bay Gneiss			
2581–2639*	Nolan Granodiorite and assoc. plutons					
		Murmac Bay Gp (2)				
2631±130			Hypersthene gneiss			
3070–3014*		Lodge Bay Granite				

NOTES: (1) Some date ranges are approximate. For references see text.
Asterisked dates are based on U-Pb zircon determinations. Wavy lines indicate recognised unconformities.
(2) The Murmac Bay Group is bracketted ca.3014–2356 Ma, and is probably equivalent to the Fay Mine complex.

Group were deposited. A similar, but more extensive graben system occurs further west, rimming the Nolan Block and underlying much of the area between Tazin Lake and Lake Athabasca. Within this system the Martin Group is underlain by the Thluicho Lake and Ellis Bay Groups in a successor basin sequence. Although no age has been determined for these successor basin groups, they were probably laid down during and immediately following the main Hudsonian cycle ca. 1900 to 1800 Ma ago.

The Train Lake Domain is largely migmatitic and granitic. Apart from along the margins, there is no evidence of an earlier Archean history. This domain coincides with Darnley's (1981) regional "Athabasca Axis" marked by negative gravity, high radiometric anomalies, and low magnetic signature. Preliminary Rb-Sr dating gives an age of 1950±125 Ma (Bell and Blenkinsop, 1984).

2. Cree Lake Zone: Remobilized Ensialic Miogeoclinal Zone to the Trans-Hudson Orogen

The Cree Lake Zone has been interpreted by Lewry and Sibbald (1977) as derived by intense pervasive and extensive remobilization of the Archean cratonic foreland during the Hudsonian cycle (Fig. 3). The zone has been divided into three domains: Mudjatik, Virgin River and Wollaston. Included also in this section are descriptions of the anomalous Ennadai-Kaminak and Peter Lake Domains.

2A. Mudjatik Domain:

The central and most extensive part of the Cree Lake Zone - the Mudjatik Domain - is dominated by felsic gneisses which are considered to be essentially Archean infrastructure. These gneisses are mostly granitoid, but locally show gneissic and laminated features suggestive of a possible supracrustal origin. Unambiguous supracrustal rocks, including metapelities, amphibolites and local iron formation, occur in narrow arcuate bands throughout the Mudjatik Domain (Munday, 1973a), defining regional-scale domes which Lewry and Sibbald (1980) have interpreted as migmatite lobes. Attained metamorphic grades are generally in the amphibolite-granulite facies transition.

2B. Virgin River Domain:

The margins of the Cree Lake Zone feature northeasterly fold trends with elongate mantled gneiss dome structures. The Virgin River Domain to the west is dominantly a granitoid terrain - in which structures are picked out by thin bands of supracrustal rocks - but along the western boundary there is a belt of greenstones and associated supracrustal rocks (the Virgin River Schists). The Junction Granite lying immediately southeast of the Virgin River Shear Zone (to which it appears to be genetically related) has been dated by the U-Pb zircon method at ca. 1820 Ma (Bickford et al., 1986) and by the Rb-Sr method at 1720±45 Ma (Bell and Macdonald, 1982).

2C. Wollaston Domain:

The Wollaston Domain to the east is dominated by the supracrustal rocks of the Wollaston Group. A number of stratigraphic successions have been proposed, depending on location in the domain and their interpretation (Fig. 3). Basal quartzites and quartz pebble conglomerates are found along the southeastern margin of the Wollaston Domain particularly at Meyers Lake and Dudderidge Lake. Pelites in the basal sequence are commonly graphitic, occurring in a thin layer immediately overlying a tectonically modified unconformity with the felsic gneisses. The overlying meta-arkoses are thick and extensive throughout the domain. The uppermost Hidden Bay Assemblage, comprising mainly quartzites and amphiboles, is reported only in the Wollaston Lake area.

Underlying the Wollaston Group are immature arkoses and amphibolites (possibly mafic volcanics) (e.g., Scott's (1970) Courtney Lake Group, Ray's (1979a) Needle Falls Group), which are exposed in thin strips along the Needle Falls Shear Zone at the eastern boundary of the Cree Lake Zone. These belong to a possible early rift sequence (Ray, 1983a, 1983b). There is current uncertainty over correlation and nomenclature for this assemblage.

Radiometric work on the basement felsic gneisses of the Wollaston Domain has yielded ages of ca. 2500 Ma. Hudsonian remobilization is also indicated in some of the granitoid rocks suspected of being Archean (e.g. Ray, 1980). Although no ages are available, the Wollaston Group is generally considered to be Aphebian at ca. 2400 to 2000 Ma. Lewry and Sibbald (1980) have suggested that supracrustal rocks in the Mudjatik Domain may also include Archean as well as Aphebian material.

2D. Ennadai-Kaminak Domain:

The Ennadai-Kaminak Domain is virtually unmapped in Saskatchewan, and its boundaries are only broadly estimated. The Ennadai Group (Macdonald, 1984) is part of a major belt of metavolcanics and metasediments which extend into the Northwest Territories through Snowbird Lake and probably correlates with the Kaminak Group (Stockwell, 1964; Taylor, 1963). Deformation is relatively low and the metamorphic grade is lower amphibolite facies. Contiguous granitic rocks appear to be high level plutons, and there is no indication of a basement. The Ennadai Group in Saskatchewan has yielded a U-Pb zircon age of 2682±5.9 Ma (Chiarenzelli and Macdonald, 1986). The Many Islands Group (Munday 1973a, 1973b) in

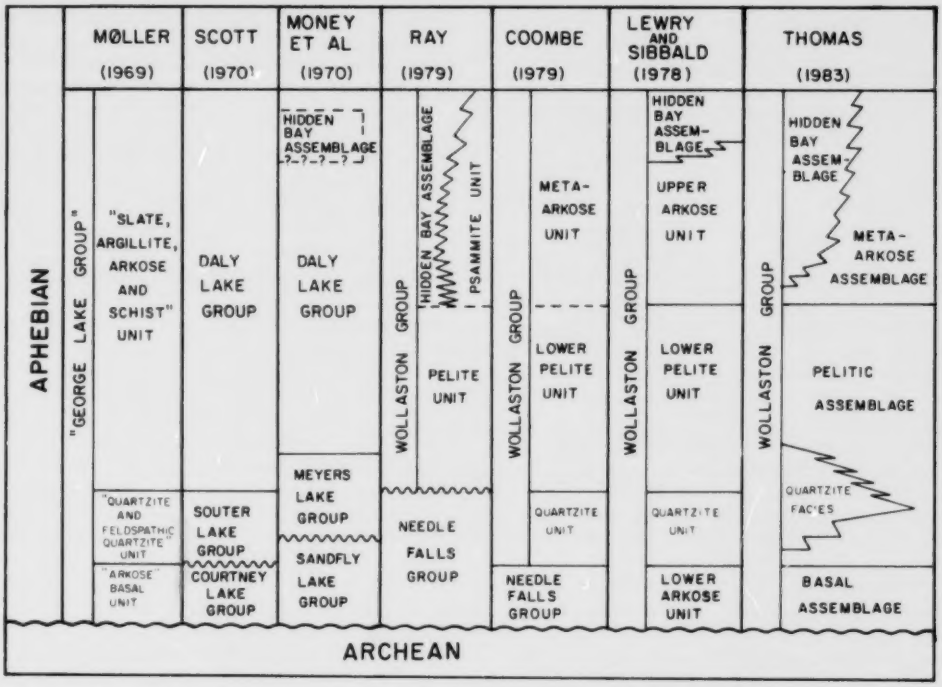


Figure 3 - Comparative stratigraphic successions in the Wollaston Domain, Saskatchewan (compiled by J. MacEachern and D.J. Thomas).

the east has been correlated with the Hurwitz Group of probable Aphebian age (Munday, 1973a, 1973b). According to Lewry (1979) the Many Islands Group overlies an infrastructural front developed from a granitoid, and presumed Archean basement.

2E. Peter Lake Domain:

The Peter Lake Domain is predominantly a bimodal plutonic complex bounded to the northwest by the the Needle Falls Shear Zone and to the southeast by the Parker Lake Shear Zone. Towards Manitoba the southeastern margin of the domain is less distinct. Mafic-ultramafic plutons with platinum group metal affinity and probable Archean age (the Swan Lake Gabbro; Ray and Wanless, 1980) are an important component. These include locally well-layered rocks of sub-alkaline continental type (Watters, 1983) as well as alkaline intrusives. The domain features remobilized granitoid gneisses resembling those in the Cree Lake Zone (Ray, 1979b; Stauffer et al., 1981). Homogeneous and little-deformed felsic granitoids are, however, more common; radiometric dating suggests that these are related to the neighbouring Wathaman Batholith of ca. 1865 Ma age.

The Campbell River Group (Lewry, 1977; MacDougall, this vol.) occupies a narrow belt within the domain. This low grade assemblage includes slates, phyllites, arenites with minor chert and mafic metavolcanic rocks. Although MacDougall (this vol.) has identified a basement, the general age and relations of the group are uncertain.

3. Reindeer Zone: Ensimatic Arc-Interarc Zone of the Trans-Hudson Orogen

The Reindeer Zone (Stauffer, 1984) is a complex region of eugeoclinal volcanic arc, plutonic and inter-arc greywacke-pelite assemblages which are considered to have lain between two convergent continental plates in this sector of the Trans-Hudson Orogen. Radiometric determinations have produced Early Proterozoic dates, largely in the range 1880 to 1800 Ma (e.g., Van Schmus et al., 1987). The generally ensimatic nature of the zone is indicated by: the absence of older basement dates, published $^{87}Sr/^{86}Sr$ initial ratios, petrochemistry of the igneous rocks, and neodymium isotope studies (e.g., Bell and Macdonald, 1982; Watters and Armstrong, 1985; Stauffer et al., 1975; Watters, 1985; Walker and Watters, 1982; Chauvel et al., 1987). Some of these studies suggest, however, the presence of a minor Archean crustal component in the northwestern part of the zone. The Reindeer Zone is bounded largely on the northwest by the Needle Falls Shear Zone.

Several workers (e.g. Lewry and Sibbald, 1980; Macdonald and Broughton, 1980) have divided the Reindeer Zone into a number of domains and belts which, although reflecting distinctions in lithostructural assemblages, probably do not everywhere adequately portray the genetic relationships of the major rock units (Fig. 4).

3A. Plutonic Facies: the Rottenstone Domain:

The Rottenstone Domain in the northwestern part of the Reindeer Zone is dominantly plutonic (Lewry et al., 1981). The Wathaman Batholith (Fumerton et al., 1984; Meyer, 1987) is part of a major late-tectonic pluton that is more extensively developed in Manitoba where it is known as the Chipewyan Batholith. In Saskatchewan, compositions are generally uniform in the range monzogranite to quartz diorite. Large sections of the batholith comprise potassium feldspar megacryst quartz monzonite, and the only variation over extensive areas is in the amount and size of the megacrysts. The northwestern margin is marked largely by the Needle Falls and Parker Lake Shear Zones, along which the latest movements post-date the batholith (Ray and Wanless, 1980). Northeastwards towards Manitoba, Wathaman-type granitoids intrude gneisses of the Peter Lake Domain. Radiometric dating by both Rb-Sr and U-Pb zircon methods gives an unequivocal intrusive age of ca. 1870 to 1860 Ma for the Wathaman Batholith (Ray and Wanless, 1980; Bell and Macdonald, 1982; Van Schmus et al., 1987).

The Rottenstone Migmatite Belt is a zone of intimately interfingering tonalite-trondhjemite intrusions and supracrustal rocks in which multiple intrusive and deformational phases can be recognized. The paleosomal rocks comprise up to about 15 percent of the terrain regionally and are mainly psammitic to psammopelitic metagreywackes similar to those in the adjacent La Ronge Domain to the southeast. Lewry (1981) and Lewry et al. (1980) have distinguished several neosomal suites, ranging from quartz-diorite-tonalite to late pink granitic aplo-pegmatites.

3B. Arc Facies of the Southeastern Domains:

La Ronge Domain.- The Central Metavolcanic Belt (Lewry, 1984; Coombe et al., 1986) of the La Ronge Domain, which is continuous to the northeast with the Lynn Lake Greenstone belt in Manitoba, includes a broad range of metavolcanic, volcaniclastic and subordinate metasedimentary rocks to which the name La Ronge Group may be given. Mafic to intermediate varieties are the most common (e.g., Harper, 1986; Thomas, 1985a, 1985b, 1986), signifying a departure from the bimodal assemblages found in some other greenstone belts. Disposed in a general regional westerly-younging homocline, the lower part of the succession includes komatiitic to bonninitic ultramafic rocks, probably both extrusive and intrusive. The upper part includes more felsic metavolcanics, which are generally overlain by tuffaceous greywacke-argillite metasediments. Metamorphic grades are generally lower amphibolite facies and there is very little pervasive regional deformation. A variety of discrete medium to small meso- to epizonal plutons occur (Harper et al., 1986b), and earlier plutons which are probably basement-derived occur in the southern part of the belt (D.J. Thomas, 1986 and this volume). Geochemical studies reveal a preponderance of low-potassium tholeiitic to calc-alkaline volcanic rocks, suggesting that the arcs developed on oceanic crust close to and possibly including a continental margin and that the associated plutons are derived by melting and fractionation of lower volcanic material (Watters, 1981, 1984, 1985, 1986).

Radiometric determinations by the U-Pb Zircon method have given ages in the range of 1876 to 1882 and 1834 to 1866 Ma for the volcanic and

Figure 4 - Outline geology of the major part of the Reindeer Zone, northern Saskatchewan.

Numbered locations: 1, Star Lake Pluton; 2, "Kisseynew Metallotect"; 3, Waddy Lake section; 4, Sahli Granite; 5, McMillan Point Granite; 6, McLennan Group; 7, Bridgman Lake Pluton; 8, Caroll Lake Gneiss; 9, Milton Island area; 10, Jan Lake.

Domains/subdomains: Kisseynew = Kisseynew Domain; MacLean = MacLean Lake Belt; Glennie = Glennie (Lake) Domain; Ukoop = Ukoop Lake Segment; La Ronge = La Ronge Domain; Crew = Crew Lake Belt; Numabin = Numabin Complex; Horseshoe = La Ronge Horseshoe terrain; Iskwatikan = Iskwatikan Subdomain.

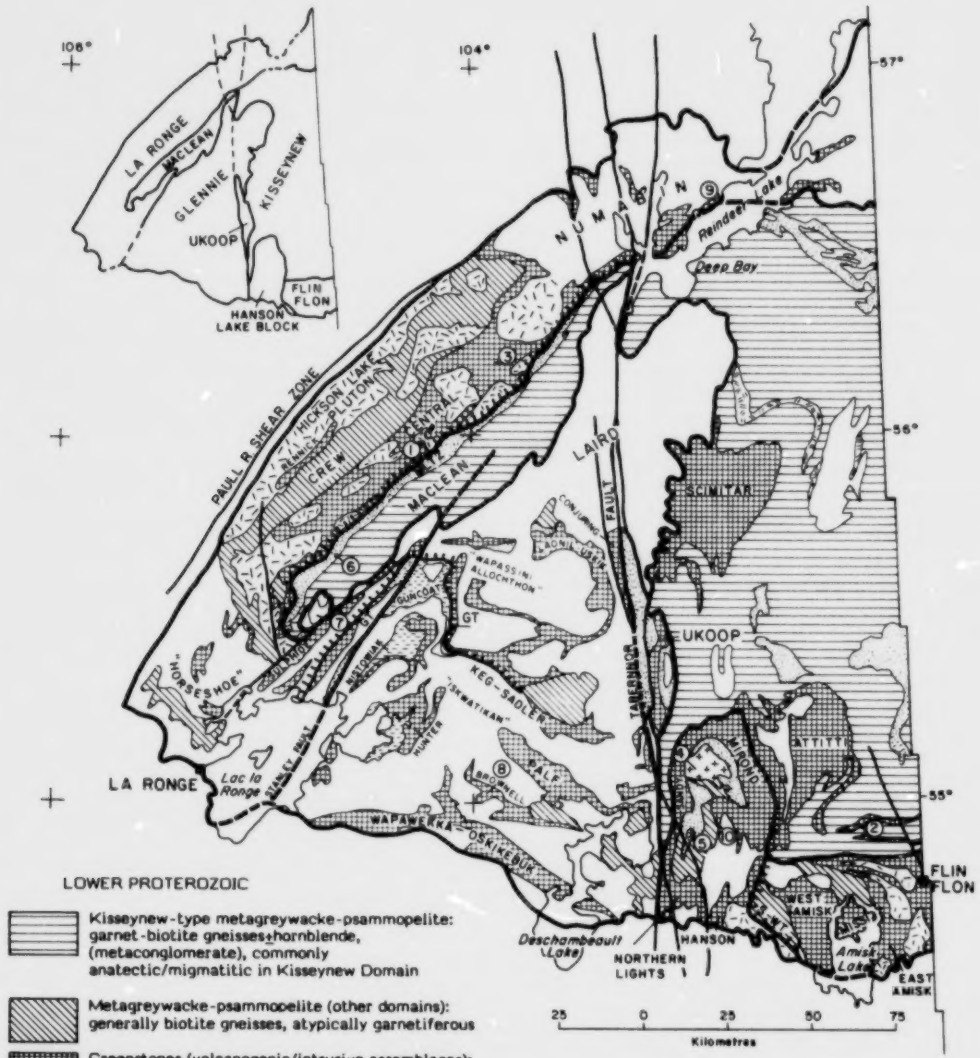
Greenstone belts: Central = Central Metavolcanic Belt; Rennick = Rennick Lake; Sulphide = Sulphide-Hebden-MacKay Lakes; Guncoat; Hunter = Hunter Bay; Wapawekka-Oskikebuk; Brownell = Brownell Lake; Palf = Palf Lake; Keg-Sadler = Keg-Sadler Lakes; Trade = Trade Lake; Laonil-Uskik = Laonil-Uskik Lakes; Conjuring = Conjuring River; Flin Flon greenstone regions: West Amisk; Missi (Island); East Amisk; Hanson = Hanson Lake Volcanics; Northern Lights = Northern Lights Volcanics.

Hornblendic gneiss complexes (volcanogenic): Scimitar = Scimitar Lake Complex; Attitti = Attitti Lake Complex; Sandy = Sandy Narrows; Mirond = Mirond Lake.

Shear zones or thrusts: MLTZ = McLennan Lake Tectonic Zone; S-WT = Sturgeon-Weir Thrust; GT = Guncoat Thrust.

plutonic rocks respectively of the Central Metavolcanic Belt (Bickford et al., 1986).

The southeastern margin of the Central Metavolcanic Belt is generally marked by the McLennan Lake Tectonic Zone, a northwesterly-dipping belt of high strain (Lewry, 1983; Thomas, 1984, 1985). Some of the smaller shear zones transecting the belt are mineralized with gold, and are the focus for current gold exploration.



The Central Metavolcanic Belt is flanked to the northwest by the Crew Lake Belt comprising mainly volcanogenic metagreywacke probably shed off the La Ronge arc in a back arc position (Lewry, 1984). The northwestern margin of the Crew Lake Belt merges through an injection zone into the Hickson Lake Pluton and migmatites of the Rottenstone Domain.

The Central Metavolcanic Belt is terminated to the northeast and southwest respectively by the Numabin Complex and the La Ronge Horseshoe Terrain. These relatively high metamorphic grade and dominantly plutonic complexes may be interpreted as infrastructural arches exposing deeper crustal levels.

Relatively fresh greenstone assemblages occur immediately east of the La Ronge Horseshoe in the Sulphide - Hebden MacKay Lakes area (e.g. Sibbald, 1986; Slimmon, 1986; Thomas, M.W., 1986). This terrain, which is regarded as a southern segment of the Central Metavolcanic Belt, contains a number of predominantly stratabound gold occurrences.

Glennie Lake Domain.- Metavolcanogenic rocks occur in the Glennie Lake Domain in narrow arcuate belts separated by granitoid gneisses and granitoids. Deformation is generally more intense than in the La Ronge Domain, and metamorphic grades are typically middle to upper amphibolite facies.

Lewry (1984) identified a major generally shallow-dipping high strain detachment zone (the Guncoat Gneisses) which separates an upper tectonic assemblage (the "Wapassini Allochthon") from the underlying "Iskwatikan Subdomain". Another regionally significant high strain zone is expressed in the Nistowiak Gneisses. The entire thrust plate package including early plutons is considered to have been subsequently refolded and intruded by later plutons, as displayed in the Laonil Lake region. The upper thrust plate sequences have been interpreted by Lewry as rooting in the La Ronge Domain to the northwest. The implied consanguinity with the supracrustal rocks of the La Ronge Domain may not, however, be fully borne out by preliminary petrochemical studies from the Laonil lake area which indicate a wholly ensimatic (tholeiitic) arc derivation (Delaney, pers. comm.).

The Glennie Lake Domain was first tentatively regarded as an older block (Macdonald, 1975) or even a possible Archean microcontinent (Lewry, 1981), but subsequent radiometric work did not confirm the microcontinent hypothesis (e.g. Bell and Macdonald, 1982; Van Schmus et al., 1987). In fact, volcanic rock U-Pb zircon ages are similar to those obtained from the La Ronge Domain at ca. 1870 Ma and the plutons range between ca. 1852 to 1836 Ma. The Caroll Lake Gneiss has yielded only a slightly older age of 1893±35 Ma (Van Schmus et al., 1987).

Recently, however, Chiarenzelli et al. (this vol.) have identified an Archean dome in the Iskwatikan Lake area which is separated from structurally overlying presumed Proterozoic rocks by further extensions of the highly sheared Nistowiak and Guncoat-type Gneisses.

Tabbernor Zone.- The eastern boundary of the Glennie Lake Domain is in part defined by the Tabbernor Zone, which includes the Ukoop Lake Segment, a "straight belt" of tight north-south periclinal folds and strong metamorphic gradients, and the Tabbernor Fault which is a major continuous mylonitic shear zone merging into later brittle faulting with regional sinistral horizonal displacement (Macdonald, 1976). North of Laird Lake, the Tabbernor Zone is represented only by later shear and brittle faults, and the domain boundary is less well defined. Delaney (this vol.) supports the notion that the Ourom Meta-arkoses were laid down in a rift environment related to early movements on the Tabbernor Fault system (Macdonald, 1976).

Stanley Shear Zone.- The western boundary of the Glennie Lake Domain has been defined by the Stanley Shear Zone, a sub-vertical belt of mylonites and tectonic schists and by late brittle faults (Lewry, 1981). This zone is probably less fundamental in nature than the Tabbernor Zone.

Flin Flon Domain.- Volcanogenic rocks of the Amisk Group are bimodal in composition, predominantly calc-alkaline, and overlain by molasse-type clastic rocks of the Missi Group (Stauffer et al., 1975; Walker and Watters, 1982; Parslow, 1984). There is little regional penetrative deformation, and the metamorphic grades rarely exceed greenschist facies. The volcanic assemblages were intruded by plutons of pre- to immediately post-Missi age between ca. 1880 to 1800 Ma ago (Sangster,1972; Bell and Macdonald, 1982; Watters and Armstrong, 1985; MacQuarrie, 1977).

3C. Inter-Arc Terrains: Kisseynew Domain and MacLean Lake Belt:

The Kisseynew Domain and the MacLean Lake Belt are metasedimentary terrains interpreted as basins infilled by greywacke-deposits largely shed off the volcanic arcs. "Kisseynew-type" rocks are mostly represented by pelitic to psammopelitic garnet-biotite gneisses and metagreywackes. Metamorphic grades attained granulite facies in some places, anatexis is prevalent, and regional pervasive ductile deformation is more intense than in neighbouring terrains.

MacLean Lake Belt.- The MacLean Lake Belt comprises volcanogenic greywackes with numerous polymict fanglomerates (collectively the MacLean Lake Gneisses) and an overlying sequence of

molasse-type meta-arkoses (the McLennan Group) which occurs in a more or less continuous strip northeastwards across the northern flanks of the Kisseynew Basin into the Sickle Group of Manitoba. Metamorphic grades in the MacLean Lake Gneisses locally attained transitional granulite facies and the group is generally very highly deformed.

The meta-arkoses of the McLennan Group abut against the Central Metavolcanic Belt for most of the way along the northwesterly-dipping McLennan Lake Tectonic Zone. Lewry (1984) argued that the Central Metavolcanic Belt is thrust over the McLennan Group from an original lower stratigraphic position, as demonstrated from way-up evidence in the overturned Haugen Lake Synform. In the Milton Island area farther north, however, meta-arkoses appear to stratigraphically underlie the volcanics (Sibbald, 1971). Lewry (1986) and Thomas (this vol.) have recently shown that in the south the McLennan Group overlies the Central Metavolcanic Belt with disconformity. The relation between the McLennan Group and the MacLean Lake Gneisses is currently unresolved.

Lewry (1984) regarded the MacLean Lake Belt as the "telescoped" remnant of a fore-arc basin.

Kisseynew Domain.- Some of the pelitic to psammopelitic rocks in the Kisseynew Domain have been referred to as the Nokomis Group. More recent terminology has borrowed the term Burntwood Supergroup from Manitoba. The true stratigraphic thickness is unknown, as the rocks are considered to be repeated and contorted by strong overfolds, nappes and thrust sheets (Pearson, 1972; Macdonald, 1975b; Ashton and Wheatley, 1986). The Attitti and Scimitar Lake Complexes contain a high proportion of volcanogenic rocks interspersed with and including anatectic gneisses. Persistent bands of mafic and calc-silcate bearing rocks can be traced over many kilometres in the southeastern part of the domain; one of these has been referred to as the "Kisseynew Metallotect" (by extrapolation from Manitoba, Gale and Ostry, 1984) on account of anomalous metal concentrations, including gold (Parslow and Gaskarth, 1985). In the north-central part of the domain, there are large volumes of anatectic granodiorite and every gradation between diatectites, metatectites and granodiorites.

The relation between the Kisseynew and Flin Flon rocks has been debated for many years. Psammitic gneisses and meta-arkose with high aeromagnetic signature and local abundant sillimanite which

Table 2 - Outline geological chronology of the Reindeer Zone, Saskatchewan Precambrian Shield

Approximate Dates (Ma)(2)	Rottenstone Domain	La Ronge-Glennie Domains	Peter Lake Domain	Hanson Lake Block	Flin Flon Domain(4)
1580				Jan Lake Granite (6)	
1773				Jan Lake Granite	
1780				Sahli Granite (5)	"Hudsonian Orogeny"
1800					Post-Missi intrusions
1800–1810					Missi Group
1810–1835					
1834–1866		Mesozonal plutons			Pluton sequence
1837		Numabin Tonalite			
1844					
1860				Bertram Bay Granite	
1863	Migmatitic neosome		"younger granite"		
1865–75	Wathaman Batholith				
1865			"younger gabbro"		
1900			gabbro pegmatite		
1885					
1976–1882		La Ronge Group (volcs)			
1888				Hanson Lake Volcs	
1893		Carroll Lake Gneiss			
2500		Iskwatikan Lake Complex		Hanson Lake Volcs? (3)	
2538				Sahli Granite	
2556–2582			Swan River Gabbro		
			"older granite gneiss"		

NOTES (1) No reliable dates are yet available from the MacLean Lake Belt and the Kisseynew Domain
(2) Dates quoted in this table are referenced in the text. Except where otherwise indicated all dates are based on U/Pb zircon determinations
(3) The Hanson Lake Volcanics date of ca. 2500 Ma (Coleman, 1970) may indicate an earlier group
(4) MacQuarrie (1977)
(5) Nd-Sm mineral dates
(6) Rb-Sr dates
(7) Wavy line indicates recognized unconformity

occur over the east-central part of the domain, have been equated with the Sickle Group of the Lynn Lake Belt and the Sheridan rocks of Manitoba, as well as with the Missi Group in the Flin Flon Domain.

Parslow and Gaskarth (1985) proposed that the Kisseynew Gneisses stratigraphically underlie the Amisk and that the Kisseynew and Flin Flon Domains are separated by a major ductile shear zone. Ashton and Wheatley (1986) have recently revived the idea of a correlation between the Amisk and the Nokomis Groups. The distinction between the Flin Flon and Kisseynew rocks may to a lesser or greater extent be a function of differences in tectonic and depositional environments northwards into the deep basin of the Kisseynew. Although generally regarded as Aphebian, no definitive radiometric information is yet available for the Kisseynew rocks in Saskatchewan.

The **Harriot Lake Enderbite** units which occur in the central part of the domain, were considered by Gilboy (1976) to represent large sills involved in Hudsonian folding. Rb-Sr dating indicates a relatively young age of 1525±80 Ma (Bell and Macdonald, 1982), but this may not be an intrusive age.

3D. Hanson Lake Block:

The Hanson Lake Block (Macdonald and MacQuarrie, 1978; MacQuarrie, 1979; Macdonald, 1981; Macdonald et al., 1986) is separated from the Glennie Lake Domain by the Tabbernor Fault in the west and from the Flin Flon Domain by the **Sturgeon-Weir Thrust** in the east. The block comprises metavolcanics, metavolcaniclastics, meta-arkoses, granitoid rocks, and the distinctive charnockitic **Sahli Granite**. In the south where metamorphic grades are low, the metavolcanogenic rocks resemble those in the Flin Flon Domain. Metamorphic grades and deformation are higher in the north where the boundary with the Kisseynew rocks is obscured by complexly refolded westerly-verging thrust sheets. The Sahli Granite has yielded late Archean dates (Bell and Macdonald, 1982; Van Schmus et al., 1987) and together with the similar **McMillan Point Granite** nearby, have been postulated as Archean mantled-gneiss dome inliers (Macdonald, 1974; Macdonald et al., 1986). Coleman (1970) obtained a near Archean Rb-Sr isochron from a suite of mixed volcanics and granites from the Hanson Lake area in the southern part of the block, but individual samples from one of Coleman's sites has yielded Hudsonian ages by the Pb-Pb and U-Pb zircon methods (Sangster, 1972; Van Schmus et al., 1987). The age of the majority of the supracrustal rocks in the Hanson Lake Block is therefore currently uncertain.

The Hanson Lake Block contains conspicuous post-tectonic aplo-pegmatitic sheets termed the **Jan Lake Granite suite**. Rb-Sr dating gave a tentative age of 1580±60 Ma for this suite (Bell and Macdonald, 1982), but a true intrusive age appears to be indicated by the recent U-Pb zircon date of 1773±9 Ma (Bickford et al., this volume). Beryliferous pegmatites close by along the Sturgeon-Weir River are probably related.

4. Athabasca Basin

The post-metamorphic Athasasca Basin is infilled with sediments of the Athabasca Group which in the centre are about 1400 m thick and cover about 100,000 km^2 in Saskatchewan and a small part of eastern Alberta. The Athabasca Group comprises fluvial to marine clastic sediments deposited during the Paleohelikan 1450 to 1350 Ma ago (e.g., Ramaekers, 1980a, 1980b, 1980c, 1980d, 1981). Apart from faulting and local thrust folding, the group is undeformed and is probably largely resting at initial shallow dips. It has also been conjectured that the basin corresponds fairly closely with its original limits.

4A. Athabasca Group:

Originally termed the Athabasca Sandstone (Fahrig, 1961), and largely comprising hematitic quartz arenites and conglomerates, other rock types are also important. Ramaekers (1980c) subdivided the group into a lower dominantly conglomeratic regressive fluvial sequence (the Manitou Falls Formation, covering the perimeter and eastern side of the basin) and a number of subsequent upward-fining, generally transgressive marine sequences. Tuffs and phosphatic units of the Wolverine Point Formation occur in the upper part of the group. Dolomites of the Carswell Formation, the youngest rocks of the group, are exposed around the Carswell Structure.

4B. Sub-Athabasca Basement:

The Athabasca Group lies unconformably on a generally well-weathered, lateritic basement regolith 50 m or more thick. This unconformity has gained much prominence on account of its association with the major field of "unconformity-type" uranium deposits (see, for example, Hoeve et al., 1980; Sibbald, 1985).

The geology of the sub-Athabasca basement has been studied by Gilboy (1982, 1983). Drill core information on the basin is limited to a perimeter zone 10 to 20 km wide and a few scattered deeper holes in the centre. The Virgin River-Black Lake Shear Zone which forms the southeastern boundary of the Western Craton can be traced in the Athabasca subsurface by means of the 1:250,000 aeromagnetic maps. The Western Craton region has a distinctively higher magnetic relief and intensity, corresponding to areas of mafic granulite facies rocks. Areas of flatter relief are equated with

garnetiferous felsic gneisses similar to those north and south of the basin. Low magnetic patterns characteristic of granitic rocks of the Clearwater type are not conspicuous outside of the Clearwater Domain. Extensive areas of Wollaston-type meta-arkoses underlain by meta-pelites have been encountered in drill core in the southeastern perimeter. Conjectured Archean domal structures are more common towards the Virgin River-Black Lake Shear Zone, and along the western margin of the subsurface extension of the Wollaston Domain.

5. Post-Tectonic Features

5A. Dykes and Late Intrusions:

Large diabase-gabbro sills which cut the Wathaman Batholith northeast of Dobbin Lake and east of Tremblay Lake have been assigned a "probably Neohelikian/Hadrynian" age (Ray, 1983a, 1983b). The Moore Lakes Complex on the southeastern perimeter of the Athabasca Basin comprises diabase-gabbro dykes, basement and Athabasca Group sediments; the dykes are post-Athabasca and dated at ca. 1100 to 1200 Ma (Ramaekers, pers. comm.).

Local post ca. 1880 Ma dyke swarms have been identified in several parts of the Shield, in number probably proportional to the detail of mapping. Major post-Hudsonian diabase dyke systems include the Beaverlodge Dykes north of Lake Athabasca (estimated at ca. 1450 Ma) and the Cree Lake Dykes along the southeastern margin of the Athabasca Basin (esimated at 1400 to 1100 Ma).

5B. Fault and Fracture Systems:

Late brittle fractures and faults commonly follow major shear zones, and may also be recognized through drainage patterns and topographic features. Regional fracture patterns are discernible on a local scale, as for example, in the Central Metavolcanic Belt, where they form parallel or conjugate systems with the McLennan Lake Tectonic Zone, and in some cases, sites for gold mineralization. Fracture systems are particularly conspicuous in the Greater Beaverlodge area, where they are, in places, associated with pitchblende veins.

A more regional system of north-south trending faults and master fractures is present in the eastern part of the Shield. It is typified by the Tabbernor Fault system, which can be traced both north into the Northwest Territories, and south of the Shield, in drainage patterns, to beyond Cumberland House.

5C. Meteorite Impact Structures:

A number of features in the Saskatchewan Shield have been identified as meteorite impact structures, although none are without equivocation. The largest of these is the Carswell Structure in the western part of the Athabasaca Basin (Harper, 1982). This approximately circular strucutre is about 35 km in diameter, and exposes the Carswell and Douglas Formations at the outer annulus. Older Athabasca rocks of an inner ring are in places highly disturbed, inverted and thrusted, presumably due to impact. An uplifted basement core about 18 km in diameter is faulted both tangentially at the perimeter and by offsetting radial faults. The basement and Athabasca rocks are intruded by the Cluff Breccia, which is generally considered to be an impact rock (Robertson and Grieve, 1975, Harper, 1982a). Other evidences for impact include the morphology of the structure, deformation lamellae in quartz, shatter cones and fractured cobbles (e.g. Currie, 1967; Pagel, 1975; Tapaninen, 1975). Impact is estimated to have occurred during the Ordovician (ca. 478 Ma; Currie, 1967).

The Deep Bay Structure at the southern end of Reindeer Lake is about 10 km in diameter (Gilboy, 1980; Johnston, 1983). Cretaceous rocks and highly fractured and shattered gneisses intersected in drill holes penetrate the bottom of the lake (Innes, 1964, Innes et al., 1964).

The smaller Gow Lake Structure is only about 5 km in diameter (Thomas and Innes, 1977; Gilboy, 1982), but has an uplifted core, exposed as Calder Island. The island is partly underlain by impact rocks, namely karnaite (fine cherty lava-like material) and suevite (rubbly "pyroclastic" rock) (Robertson and Grieve, 1975).

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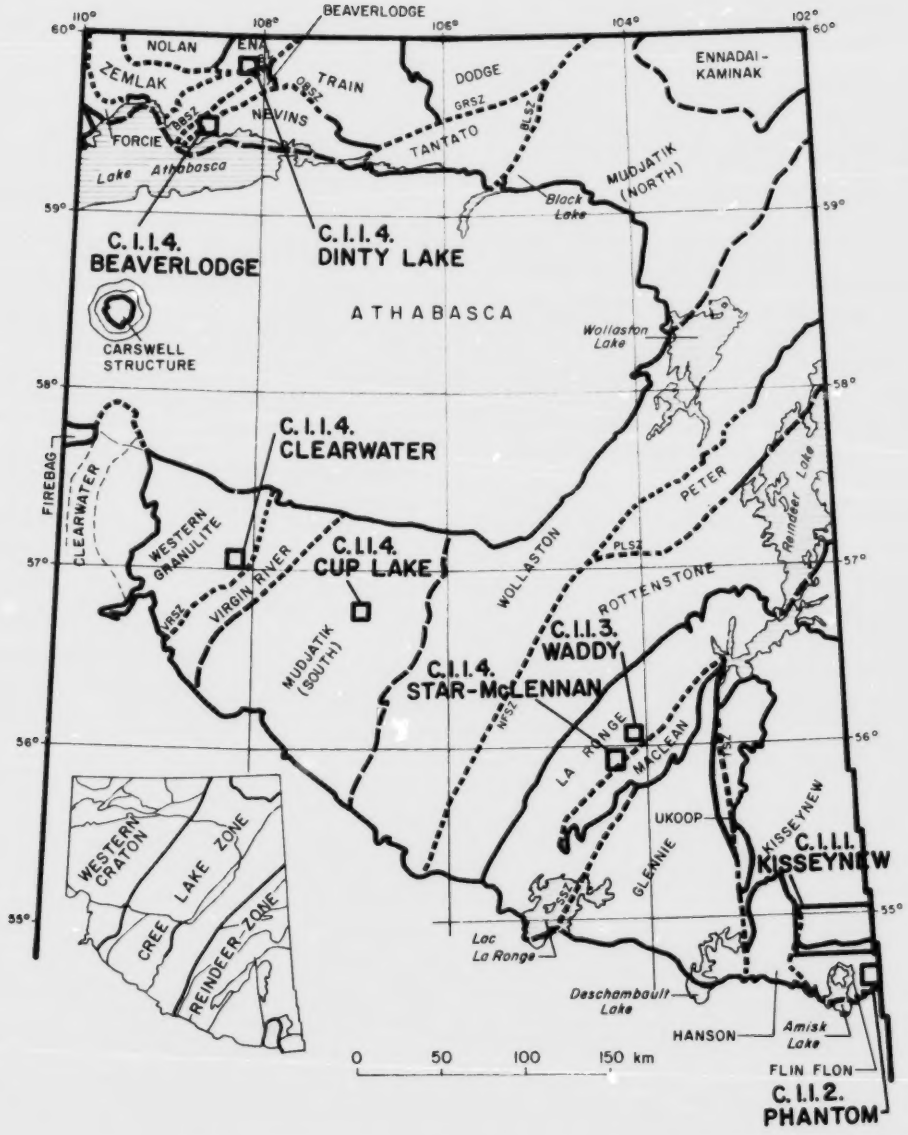
MINERAL DEVELOPMENT AGREEMENT 1984-89 PROGRAM (CANADA COMPONENT)



Location of projects mounted during 1987-88 under the Canada component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89

Structural Studies in the Northern Part of the La Ronge Domain

by K.H. Poulsen[1], D.E. Ames[1], A.G. Galley[1], I. Derome[2] and R. Brommecker[3]

Poulsen, K.H., Ames, D.E., Galley, A.G., Derome, I. and Brommecker, R. (1987): Structural studies in the northern part of the La Ronge Domain; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

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The past season's field work was devoted to completion of a project, initiated in 1984, which deals with structural aspects of gold mineralization in the northern part of the granite-greenstone La Ronge Domain. The mapping at Star Lake, McLennan Lake and Waddy Lake was specifically directed towards documentation of structures of varying scale and their potential relationship to

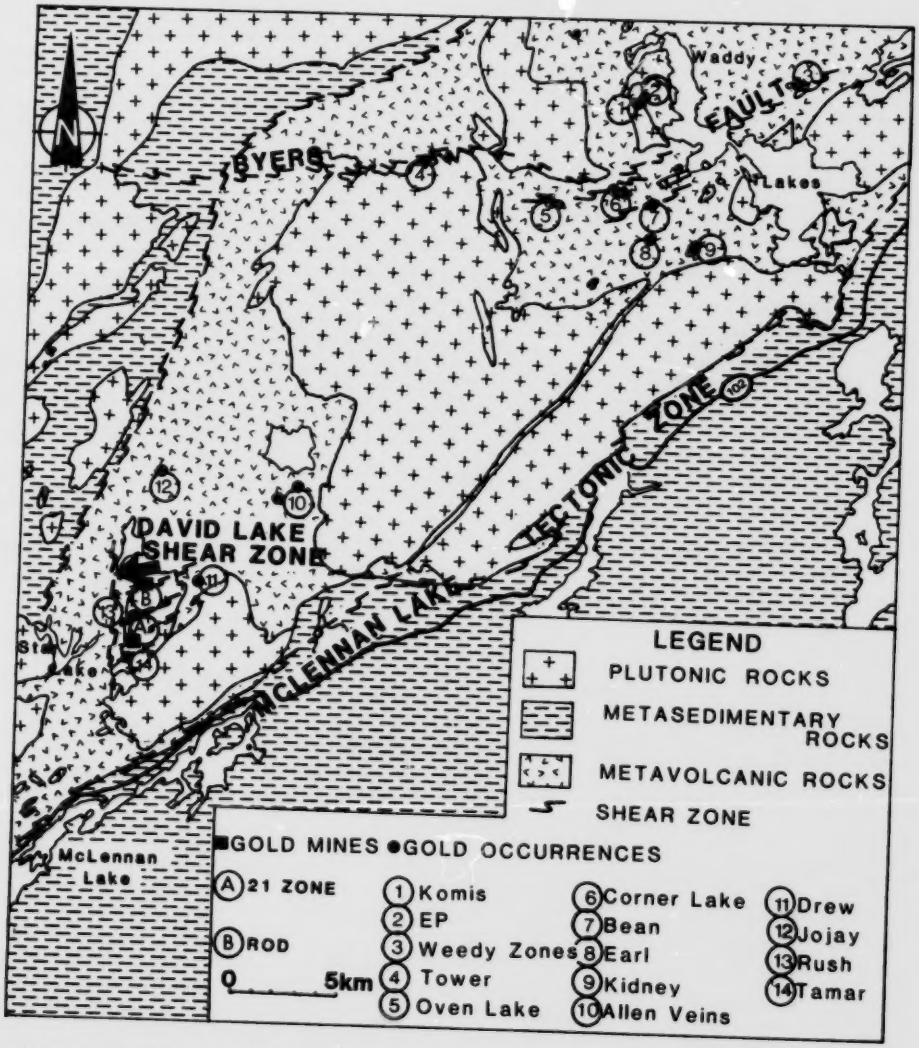

Figure 1 - Location of the northern La Ronge Domain; this study was conducted in the Star Lake area, Waddy Lake area and at the north end of McLennan Lake. Geology compiled from Harper et al. (1986).

gold. These structures range in size from large (McLennan Lake Tectonic Zone) to medium (David Lake Shear, Byers Fault) to small (the ore-bearing shear zones in the Star Lake Pluton) (Fig. 1).

Star Lake Area

The Star Lake gold deposits occur within steeply dipping ductile shear zones which transect the Star

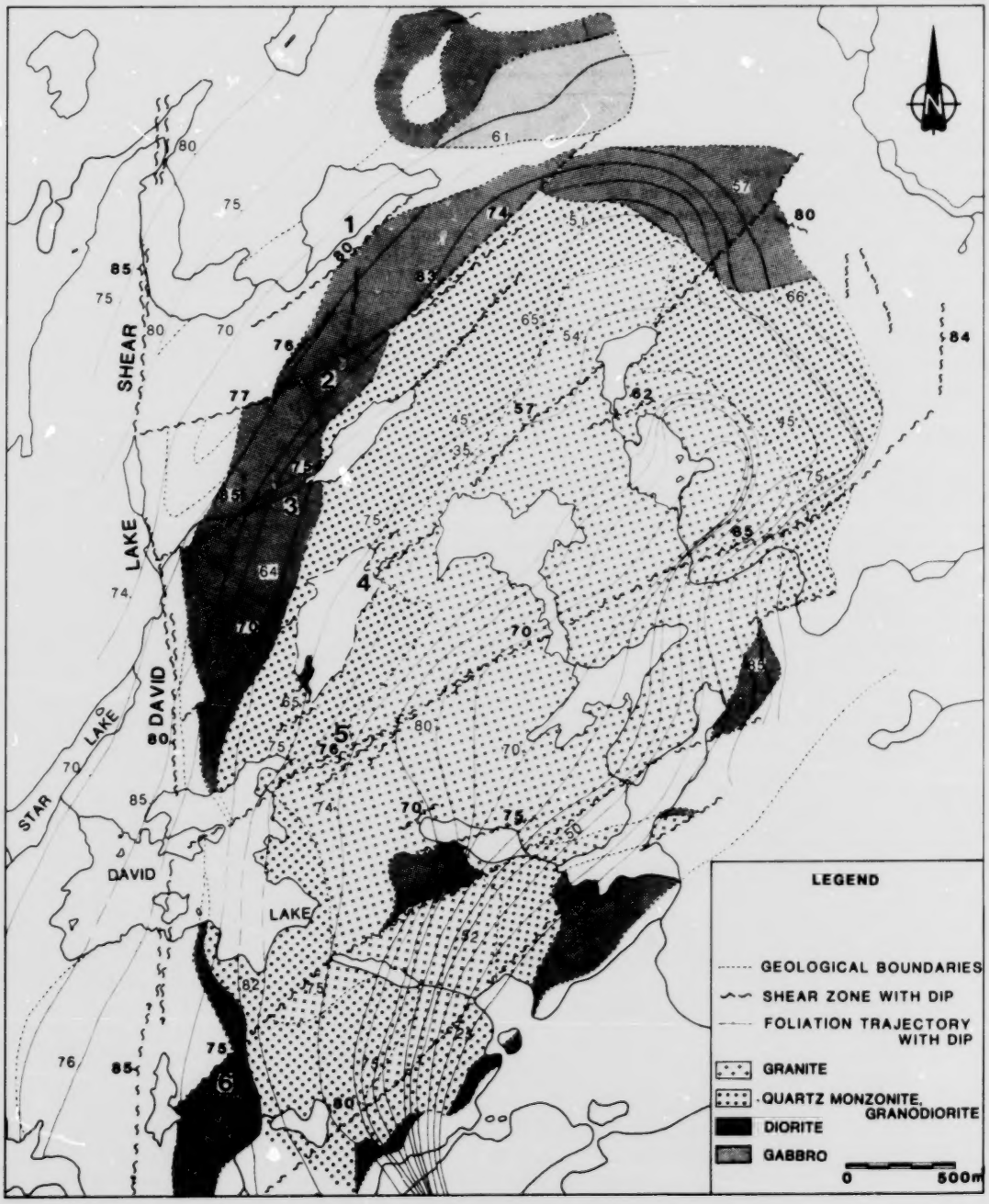

Figure 2 - Structural geology of the Star Lake area. Gold occurrences (bold numbers) include: 1, Decade; 2, Rod; 3, Rush; 4, Blindman; 5, 21 zone; and 6, Tamar.

Lake Pluton, a medium- to coarse-grained zoned granitoid intrusion (Fig. 2). The shear zones contain a prominent mineral lineation within a steep northwesterly-dipping protomylonitic foliation (Poulsen et al., 1986; Poulsen, 1986). The lineation pitches steeply to the northeast within the foliation, but both the margins of the pluton and steeply dipping dykes within it are consistently offset in a dextral sense by the shear zones. These observations were interpreted to indicate oblique shear with the greatest component in the down-dip direction (Poulsen, 1986).

This season's mapping has revealed that individual shear zones extend out from the pluton southwestward and terminate against the northerly-striking David Lake Shear (Fig. 2). This structure has been traced for a minimum strike length of 5 km and is identified by the coincidence of a pronounced topographic lineament along much of its length, a deflection in the strike of foliation in its vicinity (Fig. 2), and by truncation of supracrustal lithological units. Exposures of the David Lake Shear are rare, but a few good exposures reveal that it contains an intense northerly-striking and westerly-dipping foliation with mineral lineations pitching steeply from the north (in other terms here plunging to the west-northwest). Mineral lineations of similar orientation are not restricted to shear zones, however, and are equally consistent, though less intense, in adjacent weakly foliated volcanic rocks. This suggests that the ubiquitous "down-dip" mineral lineations in the Star Lake area are not necessarily diagnostic of slip directions in shear zones but are perhaps the product of a regional extension which was coeval with shear zone development.

McLennan Lake Area

The McLennan Lake Tectonic Zone (Fig. 1) is a major structure in the La Ronge Domain which is remarkably similar at a larger scale to the small shear zones in the Star Lake pluton. This structure was identified by Lewry (1983) as a sharp discordant northwesterly-dipping contact between metavolcanic and plutonic rocks of the La Ronge Domain and structurally inferior meta-arenites of the McLennan Group. Lewry (1983) noted that the rocks in the hanging wall of the structure are intensely foliated by comparison with equivalent rocks on a regional scale. Based on the presence of a pronounced down-dip mineral lineation and the inference that the McLennan Group metasedimentary rocks are younger than the hanging wall metavolcanic rocks, he interpreted the sharp contact as a thrust. The term McLennan Lake Tectonic Zone was applied to the structure by Thomas (1984), who demonstrated that the intensely foliated rocks extend up to 1 km northwest of the volcanic-sedimentary contact.

The past season's mapping covered a small well-exposed part of the tectonic zone at the northeast end of McLennan Lake (Fig. 3). Observations can be summarized as follows:

1) Rocks within the tectonic zone acquired their extreme foliation and lineation at amphibolite facies metamorphic conditions. Foliation and lineation are manifested by the orientation of coarse-grained metamorphic minerals and mineral aggregates, by the orientation of short and long axes of objects such as pillows and amygdules in basaltic flows, and by extreme layer transposition which is particularly evident where discordant felsic dykes are tectonically intercalated with their metavolcanic hosts (Fig. 3, inset). Static metamorphic assemblages of smaller mineral grains, also of amphibolite grade, superpose the penetratively strained tectonites.

2) Small-scale disruption of the tectonic foliation is common and, although of local extent, is of consistent style. Asymmetric Z-shaped folds (Fig. 3, inset) and asymmetric S-shaped boudins superpose competent transposed layers. These boudins possess axes parallel with the elongation direction in the same tectonites. The localized occurrence of the asymmetric folds and boudins, the variability of axial surface orientations of folds (Fig. 3) in single outcrop and the presence of coeval folds and boudins in a layer suggest that layer-parallel shearing is a viable mechanism for their formation. In this case, the component of shear must be directed approximately perpendicular to the elongation direction observed in the rocks and also must be of a dextral sense. This is not fully consistent with the style expected in a thrust regime but is compatible either with a "transpressive" shear zone in which down-dip extension outweighs dextral transcurrent shear or with transcurrent reactivation of a zone of high ductile strain such as a thrust possessing a down-dip lineation.

3) The strongest evidence that the McLennan Lake Tectonic Zone is the site of an ancient fault is presented by the brittle dislocative structures within it. These are localized near the contact between the metavolcanic rocks and meta-arenites (i.e., the trace of the thrust as defined by Lewry (1983)), and include tabular zones of cataclasite, brittle faults and localized occurrences of black veinlet material (Plate 1a) which has the characteristics of pseudotachylite injections. The cataclastic zones (of the type illustrated in Plate 1b) are typically 10 cm wide and contain randomly oriented fragments of tectonite with a pre-existing foliation; hematite and epidote are common alteration products in the cataclastic zones. The brittle faults generally contain slickenlines (Fig. 3) which indicate slip directions transverse to the steeply-plunging metamorphic lineations.

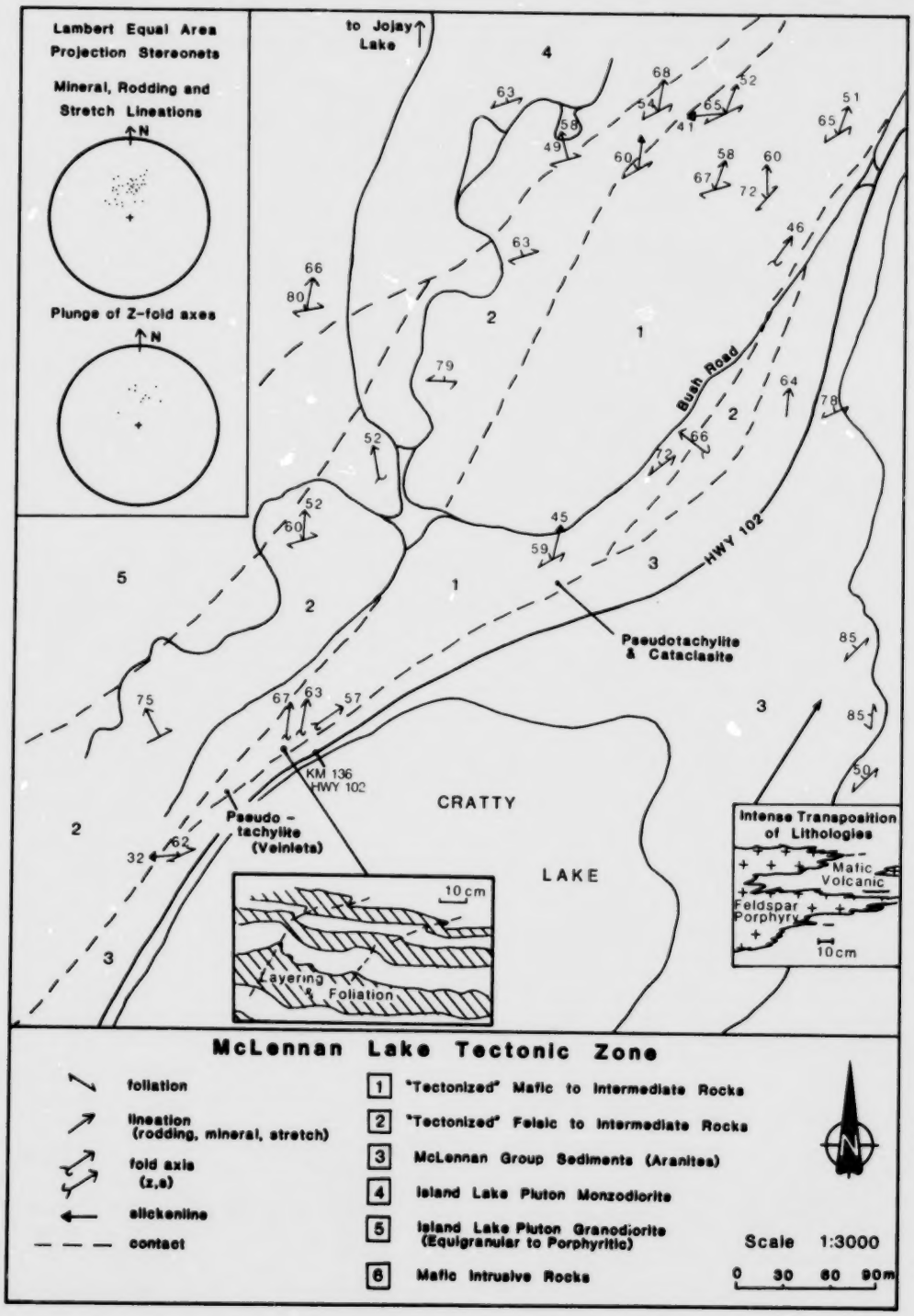

Figure 3 - Geological sketch map of the McLennan Lake Tectonic Zone near the north end of McLennan Lake. Insets illustrate the structural style at selected localities.

In summary, the McLennan Lake Tectonic Zone is likely a hybrid structure which internally shows evidence of overprinting of ductile deformational features by those of a progressively brittle nature. Our observations neither confirm nor entirely refute the possibility that it initiated as a thrust fault, but do suggest that most of the megascopic features are related to dextral transcurrent overprinting of the zone, and also that the "down-dip" lineation within it, as in small shear zones at Star Lake, is not necessarily a measure of a shear direction.

Waddy Lake Area

The Byers Fault (Fig. 1) is a prominent medium-sized structure which is spatially related to a number of gold occurrences in the Waddy Lake area. Byers (1948) noted the difficulty in identifying faults but cited the presence of "strongly sheared zones" which in some cases correspond to topographic lineaments. He also noted that there was consistency of orientation of steep sinistral and dextral brittle fractures with shallow slickenlines in the same area.

This season's mapping was concentrated on the central part of the Byers Fault in the Oven Lake - Upper Waddy Lake area (Fig. 4). The observations are summarized as follows:

1) The Byers Fault and the subsidiary Oven Lake - Corner Lake Fault to the south crosscut a sequence of metamorphosed mafic to felsic volcanic rocks with a penetrative foliation (Plate 1c) which strikes east-northeast and dips steeply north-northwest. A lineation which pitches steeply from the northeast is commonly defined by elongate clasts and phenocrysts. The fabric was developed at amphibolite facies grade, as shown by the presence of local staurolite in the zone. Intensely foliated rocks occupy a width of approximately 80 m.

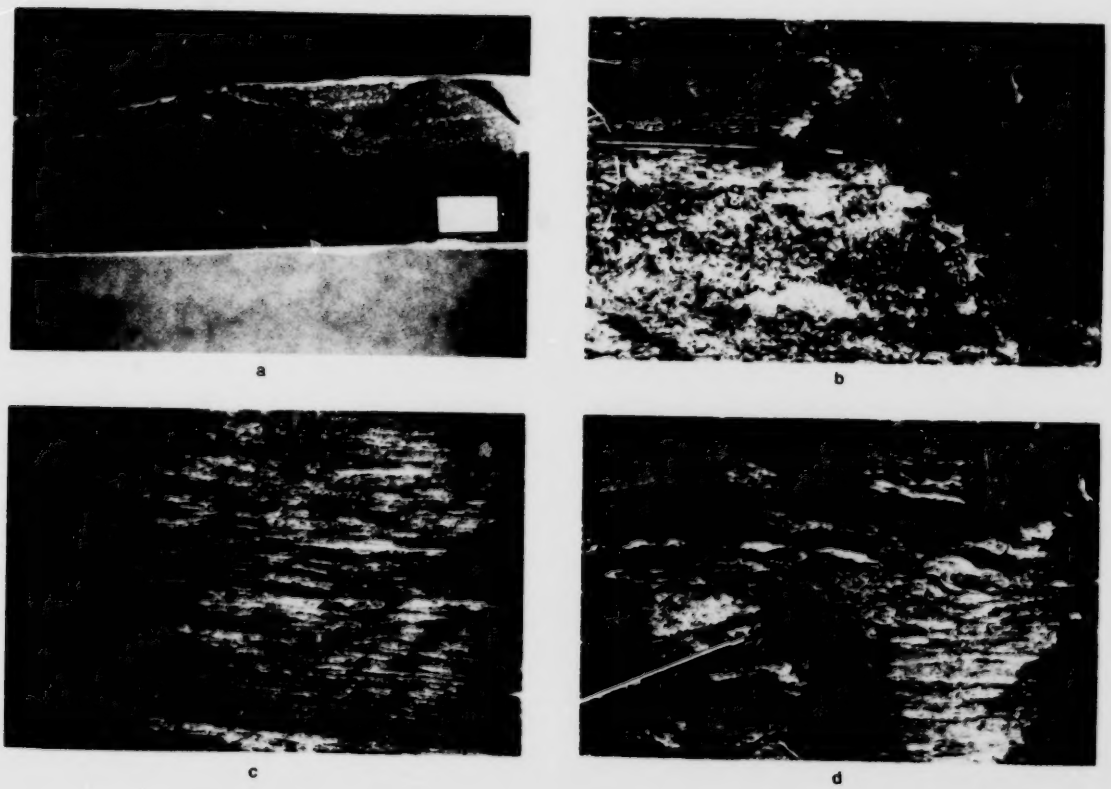

Plate 1 - a) Aphanitic veinlets cutting foliated rocks of the McLennan Lake Tectonic Zone; these are interpreted to be devitrified pseudotachylite. b) Tabular zone of cataclasite cutting foliated rocks of the Byers Fault; angular fragments in the cataclasite contain the earlier foliation and are randomly oriented. The magnet is 12.5 cm long. c) Example of the high ductile strain encountered in structures such as the McLennan Lake Tectonic Zone and the Byers Fault. This photo is from the Byers Fault, Waddy Lake area. The magnet is 12.5 cm long. d) Asymmetric kink folds and boudins overprinting tectonic foliation, Byers Fault. The magnet is 12 cm long.

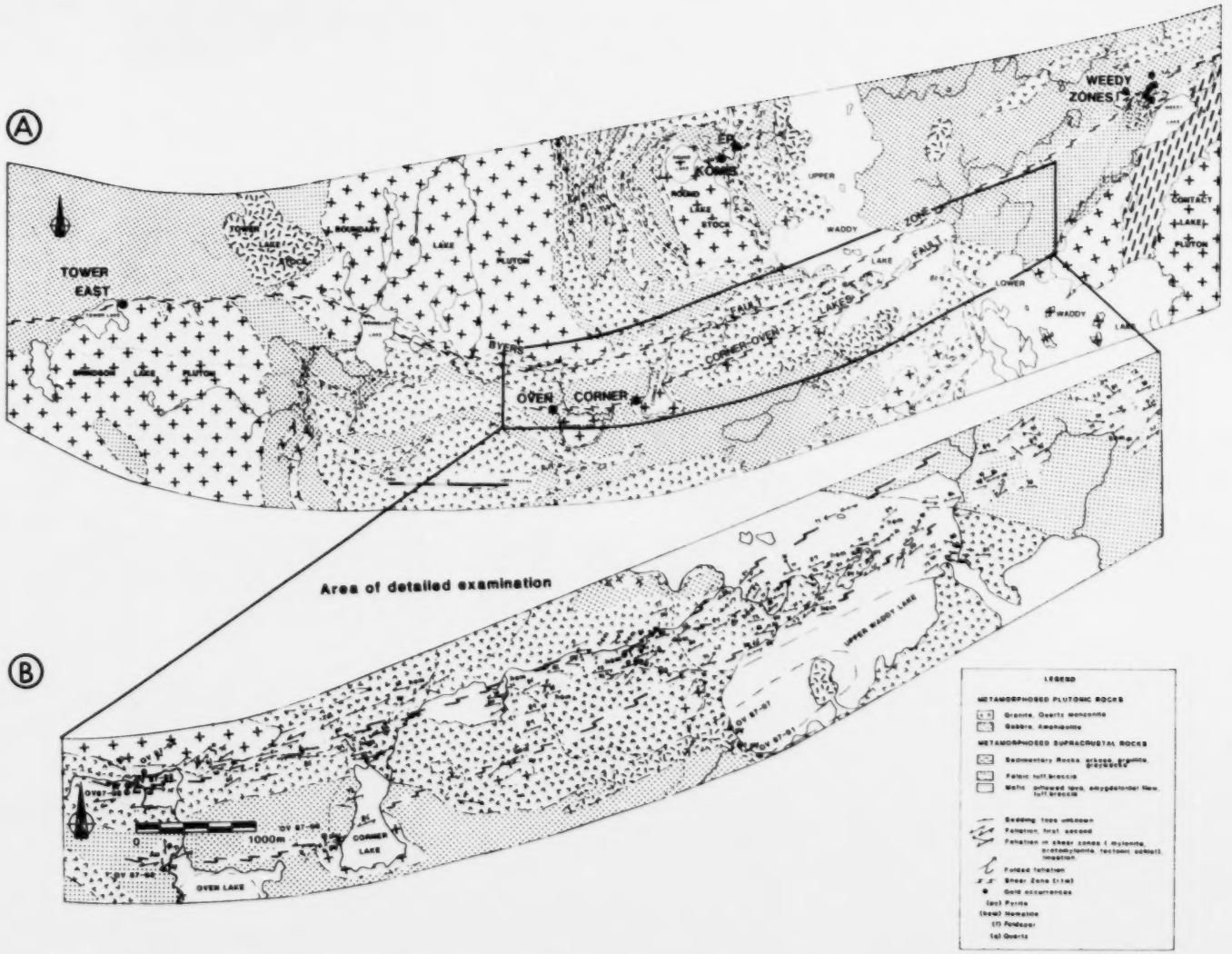

Figure 4 - Geological sketch map of the cental portion of the Byers Fault at Waddy Lake. Note the subsidiary fault through Oven and Corner Lakes. Map A was compiled from Harper (1984, 1985).

2) Disruption of the foliation is local and takes the form of Z-shaped kink folds superposed on foliation. Axial surfaces of these folds are steep and fold axes are subparallel to the mineral and clast lineations in the same rocks.

3) Brittle shear fractures typically striking 315° to 330° (sinistral) and 50° (dextral) superpose foliation and folds. These are most abundant in and adjacent to the main branch of the Byers Fault and in the Oven Lake - Corner Lake Fault, and are mineralized with hematite, epidote and a pale green clay mineral. Zones of hematized cataclasite (Plate 1d) were noted along the Byers Fault northeast of Corner Lake. In addition, chloritic fault gouge was noted in core from diamond-drill holes which cut the Byers Fault; the gouge occupies a shallow southward-dipping zone up to 10 m wide which cuts the penetratively deformed tectonites at a high angle.

Overall Features of the Structural Geology

In all of the areas of the La Ronge Domain which we have examined to date, there is evidence of a recurring pattern of deformation, and little difference in structural style between the Star Lake, McLennan Lake and Waddy Lake areas. The most prominent structural features at the outcrop scale are a steeply-dipping northeasterly-striking foliation, and a prominent direction of elongation which typically pitches northeasterly in the plane of foliation. The foliation and lineation represent ductile strains acquired during amphibolite grade dynamic metamorphism of both volcanic rocks and some of the granitoid rocks in the belt. The ductile strains are inhomogeneously distributed and are particularly intensely developed in large structures such as the McLennan Lake Tectonic Zone and in structures of medium scale such as the Byers Fault and David Lake Shear. There is no direct evidence of large displacements accompanying these structures, although they are locally discordant to and, in some cases appear to truncate, lithological units.

Static metamorphism, also at amphibolite grade, locally superposes earlier high-strain metamorphic fabrics and is presumably related to the emplacement of the youngest of the numerous coarse-grained syntectonic granitoid bodies in the area which typically possess hornfelsed aureoles. Structures of both brittle and ductile nature overprint previously strained rocks, particularly in and adjacent to the zones of existing high strain. These structures are demonstrably displacive and include brittle and ductile shear zones such as those in the Star Lake Pluton, and asymmetric folds and boudins as observed in the large- and medium-sized zones of high strain. Northerly- to northwesterly-

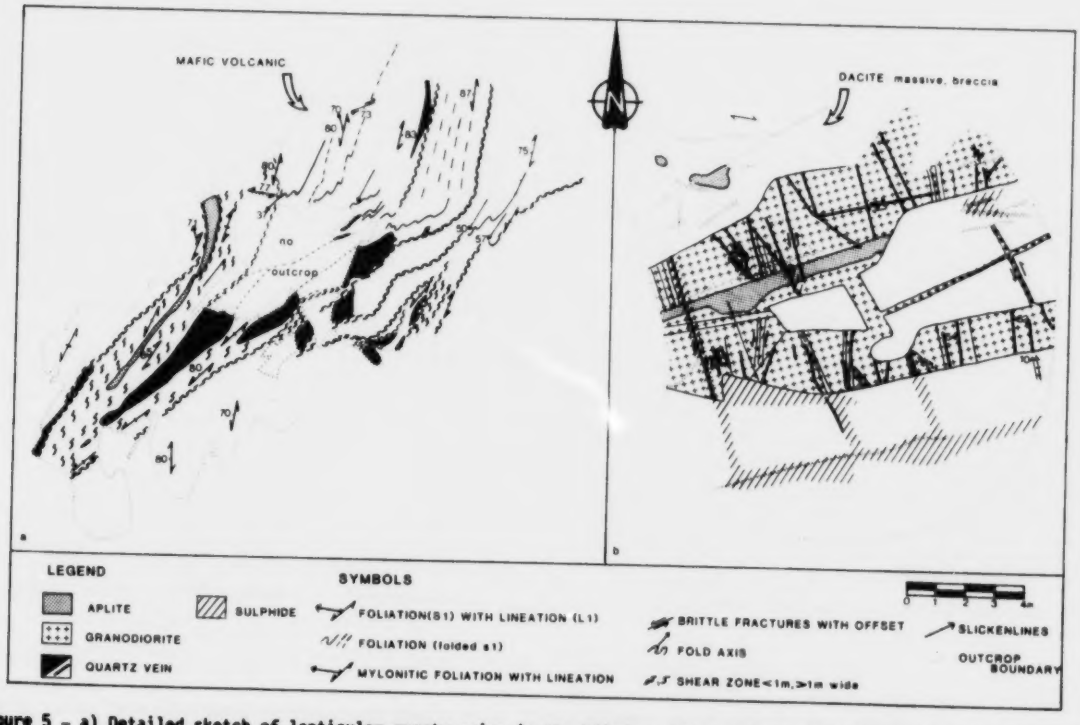

Figure 5 - a) Detailed sketch of lenticular quartz veins in the Blindman Shear Zone at its intersection with the David Lake Shear, Star Lake area. b) Detailed sketch of quartz-pyrite veins in brittle fractures, Komis deposit, Waddy Lake.

striking structures of this type have produced sinistrally offset markers whereas dextral offsets are associated with structures of northerly to northeasterly strike.

Brittle failure of the rocks in the belt is recorded by the presence of shear fractures with striated surfaces which offset markers, tabular (up to 10 cm wide) zones of cataclasite, veinlets of pseudotachylite and shallowly-dipping zones of chloritic fault gouge. The brittle fractures and cataclasites are invariably hematite-bearing, concentrated in and adjacent to zones of high ductile strain, and represent a useful field criterion to map out larger scale structures. Like the brittle-ductile structures, the brittle shear fractures are typically arranged in a northeasterly-striking dextral set and a northwesterly-striking sinistral set.

In summary, the rocks of the La Ronge Domain record a progressive history of ductile through brittle-ductile to brittle deformation. Rock displacement can only be convincingly demonstrated for brittle-ductile and brittle deformations, which appear to be of transcurrent type. The large ductile strains are characterized by northeasterly-directed shortening and strong subvertical extension, and need not have resulted in large displacements of rock packages.

The total deformational history of the domain is therefore best described as one of either transpression (Sanderson and Marchini, 1984) or combined thrusting and wrenching (Brun and Burg, 1982).

Economic Geology

Over the course of our structural studies, both in this and previous field seasons, we have examined and mapped most of the gold occurrences in the Star Lake and Waddy Lake areas. In structural terms, these can be categorized as either lenticular bodies of quartz in brittle-ductile shear zones (Fig. 5a) or as planar quartz veins in brittle shear and extensional fractures (Fig. 5b). Examples of the former are present in the Rod zone, 21 zone and the Weedy and Oven Lake deposits, and examples of the latter include Komis, Corner and Rod South. Brittle fractures containing hematite, epidote and clay minerals are common features near most of these deposits but clearly overprint the ore-bearing structures and are not directly related to the ore-forming process. The EP deposit at Waddy Lake occupies a shallowly-dipping zone of late chloritic fault gouge and may represent hydrothermal remobilization of gold.

Apart from the structural associations, there is an overwhelming correlation between gold occurrences and coarse-grained syntectonic intrusions; the veins themselves may be viewed as late-syntectonic features. Individual deposits adjacent to medium-sized zones of high ductile strain such as the Byers Fault and David Lake Shear occur primarily in subsidiary structures.

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Geological Setting of Gold, Copper, Tungsten and Molybdenum Occurrences in the Phantom Lake Region

by A.G. Galley[1] and J.M. Franklin[1]

Galley, A.G. and Franklin, J.M. (1987): Geological setting of gold, copper, tungsten and molybdenum occurrences in the Phantom Lake region; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

This is the fourth year of a five-year study, under the Canada- Saskatchewan Mineral Development Agreement (1984-89), of gold metallogeny in the Phantom Lake region, Saskatchewan (Fig. 1). In the first year of the study, gold-copper-tungsten-molybdenum mineralization was examined in the Douglas - Phantom Lakes region, and it was observed that 1) gold-copper-tungsten-molybdenum mineralization is fracture and fault controlled, 2) mineralization is present in structures that crosscut rocks of two distinct ages (the Boot Lake - Phantom Lake intrusive complex and the Amisk Group volcanic and intrusive rocks, 3) there is an apparent spatial relationship between mineralization and the Phantom Lake porphyritic granite, and 4) there are extensive zones of alteration within the granite and the Boot Lake granodiorite-diorite.

A preliminary hypothesis was formed that the gold-tungsten-copper-molybdenum mineralization represented a porphyry-type system in which metal precipitation and associated wall-rock alteration took place during fluid circulation around and through a high-level intrusion (i.e., the Phantom Lake granite). Precious and base metal concentration and deposition were controlled by a fracture system that formed during cooling and subsequent contraction of the pluton (Sutherland-Brown, 1976; Henley and McNab, 1978; Titley, 1982). In order to test this hypothesis, it was decided to complete a detailed structural analysis in and around the Phantom Lake granite in order to define more precisely the relationships between mineralization, structure and lithology.

The presence of porphyry-type alteration and mineralization in the Precambrian has been well documented in both the Churchill and Superior provinces (Ayres and Averall, 1974; Cimon, 1973; Findlay, 1976; Kirkham, 1972). Evidence for porphyry-related mineralization has been described on the Manitoba side of the Flin Flon - Snow Lake Belt by Baldwin (1980) and Stewart (1977). On the Saskatchewan side of the belt, porphyry-type mineralization has been described in the Missi Island Complex by Kirkham (1974). In the Phantom Lake area, Wallster (1979) concluded that the

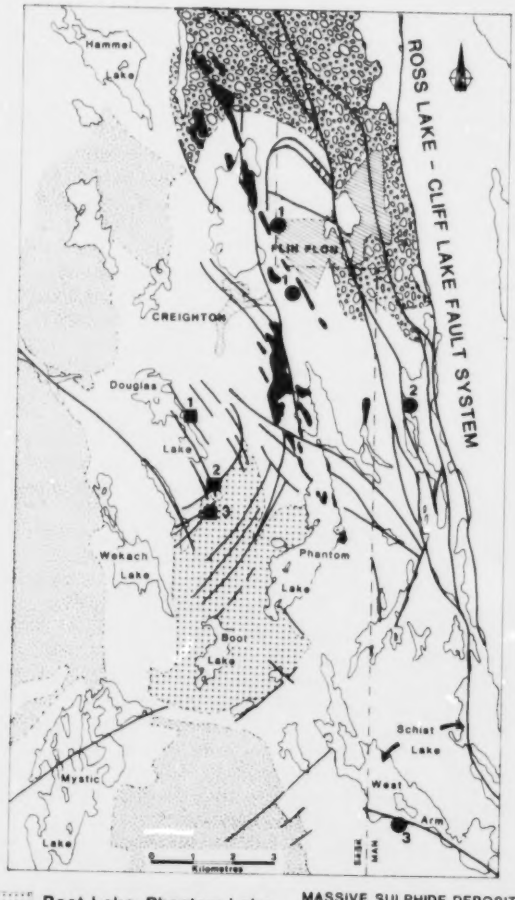

Figure 1 - General geology of the region containing the Boot Lake - Phantom Lake intrusive complex. Geology compiled from Stockwell (1960), Byers et al. (1965) and Stauffer and Mukherjee (1971).

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copper mineralization within the Boot Lake - Phantom Lake intrusive complex was related to the intrusion of that body.

Geological Setting

The Phantom Lake region is underlain by rocks of the Aphebian Flin Flon - Snow Lake Belt, a 200 km long remnant of a dominantly subaqueous island arc complex, that is overlain to the south by flat-lying Phanerozoic rocks and grades northward into the Kisseynew Gneiss Belt. Excellent reviews of the geology of the belt are presented by Bailes et al. (1987), Syme et al. (1982) and Bailes (1971). The geology of the Amisk - Flin Flon region, in which the Phantom Lake area is situated, is reviewed by Syme (1986), Pearson (1983), Bailes and Syme (1983, 1987), Stauffer and Muhkerjee (1971), Stockwell (1960) and Byers et al. (1965).

Supracrustal rocks in the area are Amisk Group subaqueous basalt flows and volcaniclastic rocks, subordinate rhyolite flows and breccia, and in the northwest corner of the map area, felsic to intermediate coarse to fine volcaniclastic units (Fig. 1). Synvolcanic intrusions are principally gabbro and diorite sills. The sequence is homoclinal, dipping southwest and younging to the southwest. The oldest member of the late tectonic intrusions in the area is the Boundary suite (Fig. 1), ranging in composition from granodiorite to pyroxene gabbro to olivine gabbro (Syme and Forrester, 1977). These intrusions are elongate parallel to the western margin of the Cliff Lake - Ross Lake Fault System (Stauffer and Mukherjee, 1971; Bailes and Syme, 1987) (Fig. 1). Their orientation relative to the fault system and the fact that the older rocks in the suite are foliated and the younger massive, allowed Syme and Forrester (1977) to conclude that the gabbros were emplaced during and after this faulting event.

The next event involved emplacement of a large, complex, zoned intrusion that was previously mapped as two separate bodies, the Boot Lake granodiorite and Phantom Lake porphyritic granite (Byers et al., 1965; Pearson, 1984). The Boot Lake granodiorite is believed to have been emplaced during an earlier deformational event than intrusion of the Phantom Lake granite (Byers et al., 1965). Field observations made during the present study indicate that the contact between the porphyritic granite and the granodiorite is gradational, suggesting a relatively short time span between emplacement of the two intrusions. At present, a U-Pb date of 1820 Ma has been obtained from the Phantom Lake granite (MacQuarrie, 1980), while a radiometric age on the granodiorite is expected in the near future (Bickford, pers. comm.).

Field observations and limited chemical analyses (Table 1; Fig. 2) indicate that there are four intrusive phases in the Boot Lake - Phantom Lake Complex (Fig. 3). The oldest phase of the complex is the most mafic, with successive phases becoming more felsic. Phase 1, the mafic phase, consists of a thin (less than 20 m wide) rim of medium-grained melagabbro. This is intruded by medium- to coarse-grained anorthositic gabbro containing pyroxenite as primary layers and as irregular dykes. The majority of Phase 1 is composed of medium- to fine-grained equigranular diorite and subordinate quartz diorite. Phase 1 rocks are observed along the western margin of the complex and as a small remnant along the east shore of Boot Lake (Fig. 3). A high magnetic anomaly below Phantom Lake could be attributed to an eastern extension of this phase (M. Koziol, pers. comm.).

Table 1 - Average Compositions from Unaltered Samples of Phases within the Boot Lake - Phantom Lake Intrusive Complex

	Phase 1	Phase 2	Phase 3	Phase 4
SiO_2	53.8	61.7	66.9	67.5
TiO_2	0.93	0.96	0.39	0.33
Al_2O_3	20.6	16.4	15.0	15.8
FeO	7.6	5.9	4.2	2.3
MnO	0.10	0.06	0.05	0.04
MgO	2.0	2.1	1.8	1.0
CaO	8.12	3.81	3.97	1.0
Na_2O	3.7	4.8	3.5	4.8
K_2O	1.25	2.7	2.29	4.87
CO_2	0.1	0.1	0.6	0.6
P_2O_5	0.28	0.38	0.1	0.19
	98.48	98.91	98.80	98.43
Ba	501	1043	524	1482
Co	19	14	12	5
Cr	23	15	21	12
Cu	22	56	22	7
La	13	24	6	33
Ni	34	40	14	51
Pb	(1)	-	14	-
V	96	98	52	25
Yb	2	1	1	1
Zn	79	110	38	68
Rb	47	45	49	53
Sr	593	1232	300	1284
Y	12	-	12	-
Zr	74	153	140	141

Oxides in percent; trace elements in ppm (except Yb which is in ppb)
(1) concentration below detectable limit

Phase 1 - Quartz diorite
Phase 2 - Quartz monzodiorite
Phase 3 - Granodiorite
Phase 4 - Porphyritic granite

Phase 2 consists of a fine-grained hornblende-biotite porphyritic quartz monzodiorite, with minor biotite porphyritic syenite. The quartz monzodiorite is intruded by dykes from the younger phases, whereas dykes from Phase 2 intrude the older diorite.

Figure 2 - Normative compositions from limited analysis of phases within the Boot Lake - Phantom Lake intrusive complex.

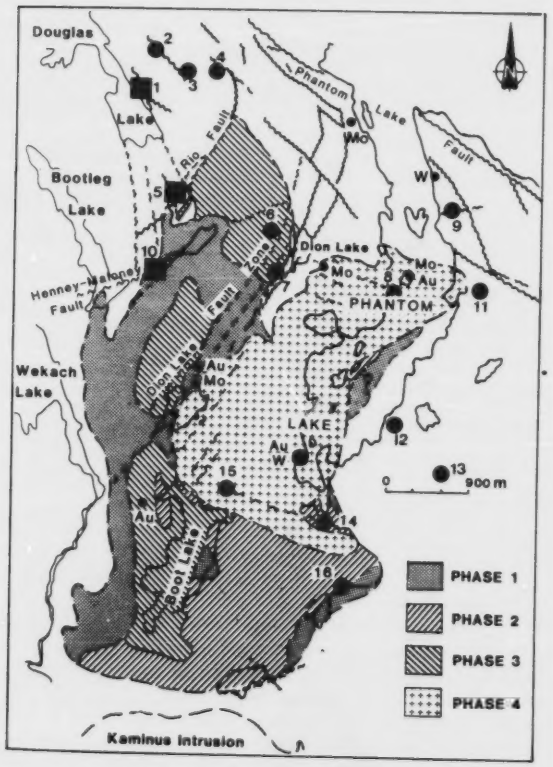

Figure 3 - Spatial relationship of mineral occurrences in the Phantom Lake region to faults and the Boot Lake - Phantom Lake intrusive complex. Numbers correlate with occurrence names in Table 2. Black squares are mines or past producers, black dots are occurrences.

Phase 3 is present as three separate stocks of fine-grained quartz-rich plagioclase porphyritic granodiorite. In places, this phase may be tonalitic (E. Syme, pers. comm.). The rock is fine to medium grained and massive.

Phase 4 consists of a fine-grained microcline porphyritic granite. The phenocrysts are euhedral, up to 2 cm in length, and display poikilitic margins indicating metasomatic growth. Minor amounts of fluorite have been observed in quartz breccia veins and as lenses between cleavage planes in biotite crystals within the granite.

Contacts between the different phases are not always visible, but most appear to be gradational, except between the Phase 1 diorites and the Phase 4 granite, where the contact is sharp. All of the Boot Lake - Phantom Lake phases are characterized by concentrations of xenoliths along the contacts between the different phases (Plate 1A). In some places, the xenoliths form 'breccia' zones several metres wide and over 10 m long. Within the diorite phase, there are large rafts of gabbro up to tens of metres long. Xenoliths are rounded to angular, and comprise Boundary intrusion rocks. The 'breccia' zones are observed to cross phase boundaries, again suggesting a close time relationship within the complex (Plate 1A).

Four periods of dyke emplacement are also observed. A swarm of mafic dykes strike northeast through the western margin of the complex. Dyke contacts are sharp where they crosscut the diorite, but contacts with the Phase 3 granodiorites vary from sharp and linear to sinuous, with individual dykes segmented and contorted. The irregular nature of the mafic dykes as they cross the granodiorite may indicate emplacement within a semimolten intrusion. This type of dyke morphology is also observed in the felsic phases of the Star Lake Pluton (Ames et al., 1987). Small aplite dykes, concentrated along the margins between the Phase 4 granite and intruded host rocks, constitute a second type. These aplites are probably related to late phase crystallization of the granite. A third dyke swarm is composed of porphyritic granite similar in composition to Phase 4. These dykes trend northwest across supracrustal rocks and all phases of the complex, although they are not observed in the core of the Phase 4 granite. A fourth generation of dykes consists of north-trending hornblende-plagioclase porphyritic rocks that crosscut all other rock types within the zone delineated by the mafic dyke swarm. Limited chemical analyses of these late dykes indicate that they show alkaline affinities.

Metamorphism

Metamorphic grade of the volcanic rocks is lower greenschist, and that of the intrusions appears to be sub-greenschist; the primary amphiboles are altered to chlorite-epidote, biotite to chlorite and

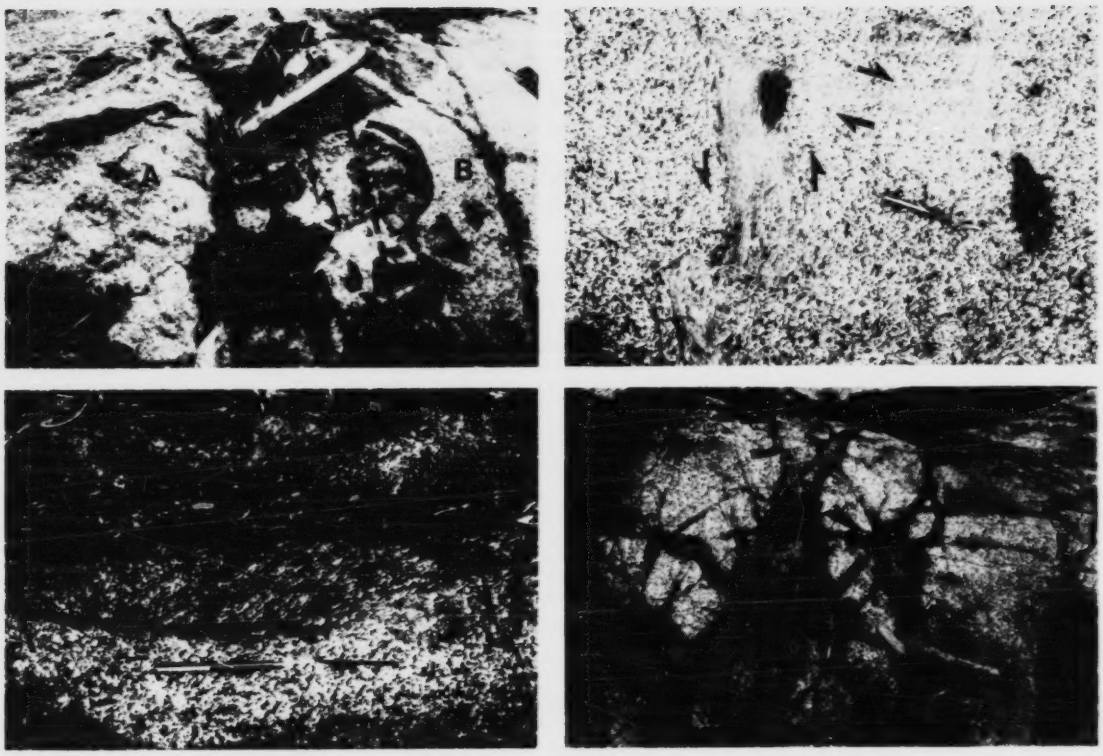

Plate 1 - A) Igneous breccia zone along the contact between Phase 3 granodiorite (A) and Phase 4 granite (B). B) Offset of sinistral east-trending shear by dextral north-northeast-trending shear. C) Strong asymmetric foliation in shear indicating dextral movement. D) Intense hematite-carbonate-epidote alteration in Phase 3 granodiorite.

plagioclase to sericite. Where the volcanic rocks are in contact with the Boot Lake - Phantom Lake complex, they form a hornfelsed aureole, up to 80 m wide, of amphibolite-grade rocks.

Structure

According to Stauffer and Mukherjee (1971) and Bailes and Syme (1987), the Amisk Group volcanic rocks and overlying Missi Group sedimentary rocks have been affected by four phases of folding with accompanying faulting. A fifth and last phase of deformation (D_5) involved a period of ductile to brittle faulting which has affected all lithologies in the area, including the syntectonic Boundary and Boot Lake - Phantom Lake intrusions. In the region immediately east of the study area, the D_5 event produced the Cliff Lake - Ross Lake Fault System, an extensive north-northwest-trending zone up to 4500 m wide and more than 12 km long (Fig. 1). In the Phantom Lake area, the D_5 event is characterized by sets of north-northeast dextral faults, including the Dion Lake and Rio Faults, and east-trending sinistral faults, including the Phantom Lake Fault (Fig. 3). The average strike of faults within these two systems varies with the host rock. The sinistral fault set has an average strike of 110^{o} in the porphyritic granite, and 60^{o} to 80^{o} in the granodiorites.

Within the study area, there is extensive faulting in a north-northeast-trending zone crossing Dion Lake, and referred to as the Dion Lake Deformation Zone. It contains both dextral and sinistral fault sets (Plate 1B), which offset one another, although the dextral system appears to be predominant.

Along the northwest margin of the Boot Lake - Phantom Lake Complex is another zone of deformation which includes the Rio and Henning-Maloney Faults (Fig. 3). This zone is dominated by dextral fault systems, with the main northeast-striking faults crosscut and kinked by northerly-trending dextral faults that can be traced for several hundred metres crosscutting the supracrustal rocks and the intrusive complex southeast of Douglas Lake (Fig. 3). The fact that the intersecting dextral fault systems contain similar gold-related alteration assemblages suggests that they are coeval. Regionally, the characteristics of the north-northeast-trending

dextral and east-trending sinistral fault systems are similar; individual fault zones are recognized by a rapid increase in the density of planar fractures parallel to the fault line, and by the development of a strong foliation. The foliation is characterized by strong banding parallel to the fault line, and a secondary asymmetric foliation between the bands (Plate 1C). The asymmetry of this foliation may be used as a kinematic indicator denoting direction of movement along the shear (Berthé et al., 1979).

The fault zones are also characterized by variably developed deformed and undeformed vein systems, the significance of which will be discussed below.

Fracture surfaces within the fault zones contain slickensides that plunge shallowly north-northeast on the dextral faults and west on the sinistral faults, indicating complementary lateral movement (i.e., both fault sets formed during the same deformational event). In some cases, displacement is distributed over several parallel fractures within the fault zones. Where brittle fracture dominates over ductile shear, dykes cut by the fault are offset by tens of centimetres across each fracture. Where ductile shearing dominates, dykes are transposed along the shear, with up to 20 m of continuous displacement observed.

The shallow tectonic transport direction indicated by both fault systems, the complementary foliation relationships within the systems and the offsetting of the systems by one another suggests that they formed as a conjugate set within a stress field which produced subhorizontal shortening. This has implications for the gold mineralization related to these fault systems that will be dicussed below.

Alteration

Three types of alteration are recognized in the Boot Lake - Phantom Lake Complex: 1) hematite-quartz-ferrodolomite-epidote, 2) sericite-ferrodolomite-quartz-pyrite, and 3) chlorite-ankerite-quartz-pyrite.

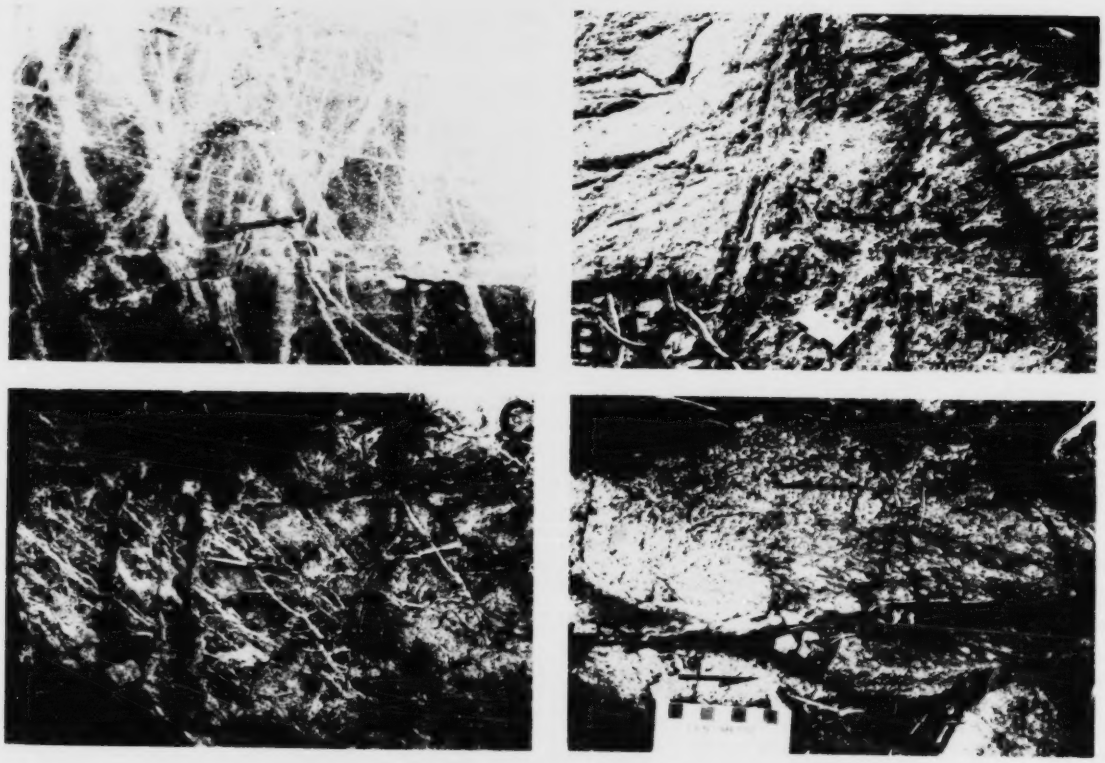

Plate 2 - A) Intense Type 1 alteration in diorite with bleaching of carbonate-epidote zones minus the hematite that is present in Phases 2 to 4. B) Type 2 sericite-quartz-carbonate-pyrite alteration controlled by planar fracture sets in Phase 4 granite. C) Quartz-albite breccia zone in east-trending zone of Phantom Lake occurrence (no. 14). D) Chlorite-quartz-pyrite-carbonate-rich shear in Phase 4 granite; typical of the mineralized phase containing precious metals.

Carbonate species were tentatively identified in the field with a carbonate stain. All of these alteration types are fracture and fault controlled, with the intensity and pervasiveness of the alteration being proportional to the fracture intensity or fault width.

The most pervasive alteration type is the hematite-quartz-ferrodolomite-epidote. It varies in character depending on host lithology. Within the porphyritic granite, fractures contain thin planar quartz veins or epidote-quartz infilling, with a 5 to 20 mm alteration halo in which framework and matrix feldspars have been hematized and carbonatized. Within the granodiorite phases, zones of quartz-carbonate-epidote form cores 10 to 20 cm wide and 30 cm long within fractures, with 10 to 20 cm wide hematite-carbonate haloes (Plate 1D). Within the gabbro-diorite phase of the complex, fractures are contained in 3 to 10 cm wide zones of bleaching caused by ferrodolomite alteration; the distinctive hematite discolouration is absent in this case (Plate 2A). This alteration type is widespread throughout all of the intrusive phases of the complex, and also forms haloes around porphyritic granite dykes where they crosscut the supracrustal rocks. The pervasive nature of this alteration type, plus the fact that it affects only rocks within the intrusive complex and those supracrustal rocks in contact with the Phase 4 granite, suggests that it is related to late-stage fluid interaction between the cooling intrusive complex and the surrounding rocks.

The sericite-quartz-ferrodolomite-pyrite alteration is fairly restricted, and has been observed principally near the southern contact between the Phase 4 granite and the Phase 2 quartz monzodiorite, within an area characterized by intensely developed northwesterly and northeasterly striking fractures. The fractures are surrounded by strong alteration, with plagioclase altered to sericite and carbonate, and biotite to chlorite and pyrite (Plate 2B). Thin irregular veinlets of quartz-(pyrite) crosscut, giving rise to a zone of patchy alteration, over 100 m long and tens of metres wide, which trends in a northeasterly direction. Other broad zones of diffuse alteration are observed within the Phase 3 granodiorite just west of Dion Lake, and within the Phase 1 rocks west of the West Arm Mine Road in the vicinity of the Henning-Maloney deposit.

The third type of alteration is mainly restricted to well-defined shear-fracture systems. Within the shears, there is heavy development of chlorite, quartz and pyrite with varying intensities of carbonate alteration. Strong carbonate alteration is most common within shears crosscutting granodiorite, diorite and basalts. In the case of the alteration zone within the Rio Fault that contains the Bootleg Lake Mine, also known as the Rio deposit, there is an ankerite-rich core surrounded by a calcite-rich periphery (Middleton, 1985). While alteration types 1 and 2 tend to be widespread due to the pervasiveness of the fracture patterns, the chlorite-quartz-pyrite-carbonate alteration is restricted to discrete zones of shearing. Alteration is observed within both the north-northeast- and east-trending faults, with concentrations within the Dion Lake Fault Zone, Rio and Henning-Maloney Faults, and within two fault zones that crosscut the north and south margins of the Phase 4 granite. Associated with this alteration type are small, undeformed, extensional quartz-chlorite-ankerite-pyrite veinlets that crosscut the shears and indicate the same sense of movement within these systems as the other kinematic indicators present. Around the larger faults such as the Rio, these extensional veins are observed for tens of metres within the granodiorite wall rocks to the fault.

Mineralization

In the region of Phantom Lake, there are numerous occurrences containing varying concentrations of gold, chalcopyrite, scheelite, molybdenite and silver (Table 2).

Occurrences have been documented by Tanton (1944), Byers et al. (1965), and Pearson (1981, 1983), with detailed studies on the Dion copper occurrence by Wallster (1979) and on the Bootleg Mine by Middleton (1985) and Pearson (1984). The Newcor and Henning-Maloney Mines produced small amounts of gold through intermittent activity, while bulk sampling of the Phantom claim assayed appreciable grades of gold and silver (Table 2). Other occurrences in the area have been examined for gold (Cor, McMillan), copper (Dion Lake) and scheelite (Douglas, IMC-B, IMC-A). The region is currently being explored by Vista Mines Inc., Saskatchewan Mining Development Corporation, and Hudson Bay Exploration and Development Co. Ltd. Vista Mines Inc. is in the late development stages with the Bootleg deposit, with quoted reserves of 183,871 tons averaging 0.35 oz./ton Au (Northern Miner, Feb. 1987).

The majority of the occurrences contain pyrite and chalcopyrite as the principal sulphide minerals, with varying amounts of accessory scheelite and molybdenite. The exceptions to this are the Newcor, Unity and Cor occurrences, where arsenopyrite is the principal sulphide mineral and sphalerite is an accessory. The presence of galena and fine-grained disseminated molybdenite commonly indicate high gold grades, as does the presence of fine-grained chalcopyrite. Occurrences containing greater than 1 percent of either coarse-grained molybdenite or chalcopyrite are commonly low in gold (M. Koziol, pers. comm.).

Three principal types of mineralization can be related directly to the alteration types previously described:

1) Quartz breccia zones, which are undeformed but aligned along the dominant north-northeasterly and easterly structural trends, and contain

Table 2 - Mineral Occurrences in the Phantom Lake Region (From Coombe (1984) and CANMINDEX Files)

Occurrence	Production	Reserves	Mineral Assemblage	Host Rock	Associated Metals
1 Newcor (Au)	20 tonnes As_2O_3 6 tonne bulk sample	40,000 tonnes of 13 g/t Au	apy, py, cpy, sph	shear in amygdaloidal basalt	Zn, Cu
2 Cor (Au)	-	-	apy, py, cpy, tm	"	Cu
3 Unity (Au)	-	-	py, po, cpy	"	Cu
4 Douglas (W)	-	-	py, apy, cpy	"	Cu
5 Bootleg (Au)	-	165,483 tonnes 12 g/t Au	py, cpy, sph, gn	shear in basalt/ granodiorite	Cu, Zn, W
6 Dion Lake (Cu)	-	-	cpy, py, po, sph	shear in granodiorite & granite porphyry dyke	Au, Ag
7 Dion No. 7 (Cu)	-	-	cpy, py, sch	shear in granodiorite and basalt	Au, Ag, W
8 CBS 766 (Ag)	-	-	py, mo	shear in porphyritic granite	Au, Mo
9 WD13 (W)	-	-	sch, py, cpy	shear in diorite	Cu
10 Henning-Maloney (Au)	690 tonnes of 29.4 g/t Au	13,500 tonnes 13.3 g/t Au	py, cpy, apy, mo	shear in diorite	Cu, Mo
11 Kar (W)	-	-	sch, cpy, po, mo	shear in basalt	Cu, Mo
12 McMillan (Au)	-	-	py, cpy, sph, gn	shear in basalt	Cu, Zn, Ag
13 Dee (Au)	-	-	py	shear in basalt and feldspar porphyry dyke	Ag
14 Phantom (Au)	450 tonnes flux 11.7 tonne bulk sample @ 65 g/t Ag 129 g/t Ag	-	py, cpy, sch, mo	shear in granodiorite	Ag, Cu, Mo, W
15 IMC-B (Au)	-	-	py, sch	shears in porphyritic granite	W
16 IMC-A (Au)	-	-	py, sph, gn, cpy	shears in granodiorite/ diorite	Ag, Cu

variable amounts of potassium feldspar, albite, pyrite, chalcopyrite and fluorite, appear to be related to the Type 1 hematite-quartz-epidote-carbonate alteration. These zones are common in the Phase 4 porphyritic granite, and in the Phase 2 granodiorite at the south end of Phantom Lake where it is surrounded by the Phase 4 granite (Fig. 3). They vary in composition and size from quartz-(fluorite) veins 10 cm wide and 1 m long, to 2 m diameter circular zoned bodies formed by quartz-microcline rings interlayered with wall rock, to extensive breccia systems up to 15 m wide and 100 m long (Plate 2C). The larger breccia systems contain scattered concentrations of coarse pyrite and chalcopyrite but very low concentrations of gold.

2) Another type of mineralization is related to the fracture-controlled diffuse sericite-quartz-carbonate-pyrite alteration zones containing numerous irregular veinlets of pyrite and chalcopyrite, in which the sulphide minerals occur as marginal disseminations. An example of this occurrence type would be the Dion Lake copper occurrence (No. 5 on Fig. 3).

3) A third type of mineralization is associated with chlorite-quartz-carbonate-pyrite alteration. It comprises deformed and planar quartz-ankerite-sulphide veins within, or close to, shear and fracture zones displaying variably developed carbonate alteration and associated disseminated sulphides. Small well-defined mineralized shears are composed of strongly foliated and altered rock with planar to boudinaged quartz-ankerite-sulphide veins along the centre axis (Plate 2D). Small extensional ankerite-chlorite-quartz-pyrite veinlets, previously described as Type 3 alteration, are the latest feature within these shears. The gold content is apparently dependent upon the presence of the quartz-ankerite veins, rather than on the intensity and extent of the alteration (M. Koziol, pers. comm. 1987).

Summary and Conclusions

The Boot Lake - Phantom Lake Intrusive Complex is a high-level zoned intrusion which was emplaced late during the regional deformational event responsible for the formation of the Ross Lake - Cliff Lake Fault Zone. A high level of intrusion is indicated by the fine-grained porphyritic texture of most of the phases, and the presence of numerous breccias dykes along interphase contacts. The late timing of the intrusion is apparent from crosscutting relationships with the Boundary Intrusions, the lack of a pervasive tectonic fabric indicative of involvement in a regional folding event, and the fact that the emplacement of dyke swarms coeval with the intrusive complex was controlled by the D_5 faulting in the area. A late intrusive age is also indicated by the U/Pb determinations and by the presence of fluorite in at least one phase. Fluorite is characteristic of anorogenic intrusions related to the basin-and-range type of tectonism in the southwestern United States (Christiansen et al., 1983).

Of the three types of alteration and mineralization spatially associated with this zoned intrusion, there is a strong possibility that the hematite-quartz-carbonate-epidote type (and associated copper-tungsten-molybdenum mineralization), and the sericite-quartz-carbonate type (and associated tungsten-copper mineralization) are genetically related to a porphyry system. These alteration types are pervasive but patchy, restricted to the intrusion and controlled on the small scale fractures that mimic the larger fault systems that were active during emplacement of the intrusion. Control of mineralization within a porphyry system by regional tectonic stress that was active during the emplacement and cooling of a pluton is well documented in the southwestern United States (Heidrick, 1974; Heidrick and Rehig, 1972; Heidrick and Titley, 1982). To date, the precious metal contents of these two alteration types have been found to be elevated but not economic.

A later phase of chlorite-quartz-ankerite-pyrite alteration and associated gold-(silver) mineralization is controlled by a conjugate system of dextral north-northeast-trending and sinistral east-trending faults that in some cases crosscut and overprint previous alteration zones. Gold, and varying proportions of silver, are concentrated in quartz-ankerite-sulphide veins within the altered fault zones. For this reason, the concentrations of gold with the greatest economic potential found so far in the region are controlled by this strike-slip conjugate fault system.

In theory, within these strike-slip systems, the direction of maximum dilation will be perpendicular to the tectonic transport direction. Within the altered portions of the fault zone, gold-rich zones should then be plunging at a steep angle to the south-southwest in the dextral faults, and to the east in the sinistral faults. It will be interesting to see if this theory is supported by development of the ore shoots at such deposits as the Bootleg.

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Investigation of Mafic and Ultramafic Rocks, and Platinum Group Element Mineralization in Northern Saskatchewan: Preliminary Findings

by Larry Hulbert[1]

Hulbert, L. (1987): Investigation of mafic and ultramafic rocks, and platinum group element mineralization in northern Saskatchewan: preliminary findings; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

During the 1987 field season, mafic-ultramafic rocks and platinum group element (PGE) investigations were conducted at four localities in northern Saskatchewan: the Greater Beaverlodge area, Dinty Lake, Cup Lake and the Fournier - Careen - Camel Lakes area.

A) Fournier - Careen - Camel Lakes Area

The Clearwater Anorthosite Complex, associated bodies and mineralization was investigated in the Fournier Lake, Careen Lake and Camel Lake area of the Western Granulite Domain (Sibbald, 1974; Lewry, 1974).

Clearwater Anorthosite Complex

Detailed field investigations along an east-west section from Fournier Lake to the Clearwater River disclosed that the anorthosite complex consists of a well-layered cumulate sequence facing in an easterly direction. The cumulate sequence consists of anorthosite, noritic anorthosite, anorthositic norite, norite, gabbronorite, feldspathic bronzitites, bronzitites, magnetite gabbro and Fe-Ti spinel-rich layers. The bulk of the layered sequence is noritic anorthosite in composition. The cumulate layering trends northeast to north-northeast and dips on average 35°E. The rocks in this area are extremely well exposed (up to 70 percent in places) and well preserved. Samples containing fresh orthopyroxene, clinopyroxene, plagioclase and phlogopite from areas retaining cumulate textural features were sampled for Nd-Sm and Rb-Sr isotopic investigations and age determinations.

Although this complex has all the characteristics of massif-type anorthosite intrusions (Gochnauer, 1978) it is unlike other known massif-type anorthosite bodies in that it contains anomalous levels of sulphides. In the central portion of the complex, between Fournier Lake and the Clearwater River, numerous stratabound and, in one case, stratiform sulphide concentrations were found. The stratabound occurrences consist of discontinuous irregular zones of Cu-rich sulphides in a noritic anorthosite host. These mineralized zones may be as small as 0.3 m in diameter, whereas the larger ones locally attain lengths of 18 m and widths up to 3.3 m. The sulphide concentrations are generally in the 1 to 3 percent range; however, samples containing up to 6 percent sulphides have been noted. One stratiform horizon which was found to contain 2 to 3 percent disseminated sulphides over a thickness of 0.3 m could be traced along strike for at least 70 m and is open to the northeast.

Pt, Pd and Au analyses indicate that the mineralization in the investigated portion of the layered sequence is barren in terms of PGEs. The highest Pd, Pt and Au values are 3, <15 and 8 ppb, respectively. The highest Au value (84 ppb) was found in a 10 cm thick Fe-Ti spinel-plagioclase cumulate layer containing approximately 50 percent spinel.

Camel and Careen Lakes Area

Massive and semimassive concentrations of pyrrhotite-rich sulphides were examined at Camel Lake and Careen Lake. The Careen Lake occurrence is the most extensive and well-exposed representative of this type of mineralization and thus will be discussed further.

Mineralized norites, feldspathic bronzitites and bronzitites occur along the north shore of Careen Lake. The norites appear mineralogically and texturally identical to the more mafic norites found in the main mass of the Clearwater Anorthosite Complex to the west. It is inferred that these less fractionated intrusions represent early sill-like differentiates synchronous with the emplacement of the main Clearwater Anorthosite Intrusion. The proximity of these intrusions to the main anorthositic mass, the mineralogical and textural similarity to the early norites found within the complex, and the observed crystallization order of the various silicate phases suggests that the mineralized norites and pyroxenites are the equivalents of the earliest differentiates of the parental magma that gave rise to the Clearwater Anorthosite Complex. Thus, similar lithologies and mineralization may also be expected in the basal portion of the complex.

The mineralized bodies are typically noritic in composition and intrude quartz-biotite-garnet± orthopyroxene paragneisses. Massive sulphide

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concentrations at least 0.8 m thick occur at the base of the sills and pass upwards into net-textured pyroxenites, feldspathic pyroxenites and norites. The silicate-sulphide textural relationships leave little doubt that this mineralization is of the magmatic segregation type. Also, it is inferred that the anomalous concentrations of sulphide in these sill-like bodies and in the layered sequence of the Clearwater Anorthosite Complex are the result of sulphur contamination from the adjacent metasediments.

Analyses of the semimassive and massive mineralization reveals that these sulphides also contain very low levels of Pt, Pd and Au. The higest Pd, Pt and Au analyses gave values of 52, <30 and 204 ppb respectively. The computed average values for these elements are 27, <15 and 76 ppb respectively.

B) Cup Lake Area

Two different geological environments were investigated in the Cup Lake area of the Mudjatik Domain (Lewry and Sibbald, 1977) for their PGE and gold potential: the Cup Lake Ultramafic Complex and the radioactive pegmatoids.

Cup Lake Ultramafic Complex

The Cup Lake Ultramafic Complex is the largest known ultramafic intrusion in the Mudjatik Domain. Lithologically and structurally the intrusion is typical of ultramafic intrusions found elsewhere in the Mudjatik Domain.

The main mass of the Cup Lake Ultramafic Complex occurs along the north and east sides of Cup Lake where it attains a strike length of approximately 4.0 km and a thickness of 0.25 km (Munday, 1977). Detailed field examinations disclosed that the ultramafic intrusion is a fairly well layered sill-like body consisting of ortho-pyroxenite, websterite, harzburgite and minor dunite of cumulate origin. Subsequent metamorphism has transformed many of these rock types into amphibole-rich assemblages (hornblendites).

Wave-washed exposures along the east shore of the lake display small-scale cumulate layering of harzburgite and pyroxenite. At this locality, the harzburgites form the basal member of the cyclic unit and are generally about 20 cm thick and capped by a 5 cm thick layer of orthopyroxenite or websterite. Exposures of dunite examined at other localities disclosed that the basal member of these cyclic units, when fully developed, is dunite. Thus, the ultramafic cumulate rock type differentiation order at Cup Lake is dunite, harzburgite, orthopyroxenite and websterite. Relict cumulate structures tend to suggest that the layered complex is facing towards the east. Suitable lithologies were selected for Nd-Sm isotopic analyses and age determinations.

Sulphide mineralization is very rare in the complex. Trace amounts of sulphides have been noted in some places as inclusions in large orthopyroxene porphyroblasts within the harzburgites. Chalcopyrite-rich (2 to 3 percent) mineralization was observed at one locality in a pyroxenite segregation band in a harzburgite layer. The highest Pd, Pt and Au values obtained were 16, <15 and 62 ppb respectively. The average values are 10, <15 and 10 ppb respectively, based on 11 samples.

Radioactive Pegmatites

The radioactive pegmatites along the northwest and west sides of Cup Lake were investigated for their Pd, Pt and Au contents, since it is known that some of the radioactive occurrences in the Greater Beaverlodge area of northern Saskatchewan contain anomalous levels of PGE and Au when in the vicinity of ultramafic bodies. All samples returned values of <2, <15 and <1 ppb Pd, Pt and Au respectively.

C) Dinty Lake Locality

The so-called noritic intrusions in the Dinty Lake area (33 km east-northeast of Uranium City) have long been known to contain anomalous levels of Ni and Cu mineralization (Blake, 1955). The main intrusion and mineralization at Dinty Lake is exposed in eight trenches and scattered outcrops for at least 300 meters along strike and has a maximum surface width of 65 meters.

Field examinations have shown that the so-called noritic body was originally a layered intrusion consisting of anorthosite, anorthositic norite, norite, feldspathic pyroxenite, pyroxenite and mineralized equivalents. Metamorphism subsequent to the granulite facies has given rise to garnetiferous equivalents in the more anorthositic differentiates. Original sulphide-silicate textural features are well preserved in the more sulphide-rich lithologies. Specimens from the mineralized zones show excellent examples of magmatic sulphide-silicate segregation features. The modal proportion of sulphides was observed to increase in passing from a footwall of norite to an overlying thin (8 to 10 cm) orthopyroxenite layer upon which subsequent concentrations of semimassive and massive sulphides were deposited. Within the massive sulphides, spherical inclusions of orthopyroxenite and net-textured orthopyroxenite occur suspended in the sulphide-rich matrix and impart a grape-shot appearance to the mineralization. The presence of these inclusions, as well as other sulphide-silicate textural features, clearly indicates that sulphide segregation from the Dinty Lake magma occurred after a period of

plagioclase-orthopyroxene and orthopyroxene cumulate activity. This style of mineralization appears to have been cyclical during the crystallization history of this intrusion. These features leave little doubt that the Dinty Lake noritic bodies and associated mineralization are of a magmatic origin.

It is interesting to note that these observations on the Dinty Lake noritic body are identical to the descriptions of the so-called noritic bodies in parts of the Fond-du-Lac - Stony Rapids region (Colborne, 1960, 1962; Colborne and Rosenberger, 1963) which host large tonnages of low grade Ni-Cu-Co mineralization.

Nd-Sm isotopic investigations and age determinations are being conducted on samples from the Dinty Lake intrusion. Pd, Pt and Au assays carried out on mineralized samples from Dinty Lake give maximum Pd, Pt and Au values of 146, <15 and 548 ppb respectively. The average values for sixteen samples are 81, <15 and 194 ppb respectively.

D) Greater Beaverlodge Area

Field and laboratory investigations on the U-Au-PGE and Au-PGE mineralization in the Greater Beaverlodge area continued during 1987. In addition to the Nicholson Bay and Fish Hook Bay localities, which are the type areas for U-Au-PGE association, numerous other radioactive and nonradioactive occurrences in the Greater Beaverlodge area were investigated for their Pd, Pt and Au potential.

The Eagle Group

Numerous trenches exposing pitchblende, pitchblende and sulphide, and sulphide mineralization occur on the Eagle Group northeast of Hal Lake (Christie, 1953). The highest Pd, Pt and Au values obtained from the radioactive mineralization were 23, 23 and 24 ppb, respectively. In all remaining samples (radioactive and nonradioactive), the Pd and Pt analyses are below the detection limit of 2 and 15 ppb respectively. The average Au value from this locality is 9 ppb.

Material collected from the Eagle Mine site also gave low Pd, Pt and Au values of 2, <15 and 5 ppb. Material representative of the ore was not obtainable.

Nesbitt-Labine Uranium Mines Ltd. - ABC Mine

The Pd, Pt and Au contents of sampled mineralization from this site are very low. The Pd content varies from 2 to 5 ppb, Pt is <15 ppb and the Au content ranges from <1 to 19 ppb.

Cayzor Athabasca Mines Ltd. - Cayzor Mine

With the exception of one relatively high Au value (103 ppb), the precious metal content of the Cayzor mineralization is low. Values are 3 to 11 ppb Pd, <15 ppb Pt and <1 to 103 ppb Au.

Eldorado Nuclear Ltd. - Padge Bay Mine

Limited mineralized material obtained at this locality revealed values of <2 ppb Pd, <15 ppb Pt and 10 ppb Au.

Lodge Bay - Locality 19A

A high-grade pitchblende occurrence in a meta-gabbro west of Lodge Bay, referred to as occurrence 19A (Beck, 1969), was examined and sampled in considerable detail. The massive pitchblende is confined to a north-northeast-trending shear zone and varies in thickness from 10 to 35 cm. The highest Pd and Pt values obtained were 6 ppb and <15 ppb, respectively. However, gold values up to 1.28 oz./ton were obtained. Detailed sampling across the mineralized zone disclosed that the precious metals do not appear to have a site preference within the pitchblende veins.

Quartz and quartz-sulphide veins also occur at Lodge Bay in the vicinity of locality 19A. These veins tend to be orthogonal in direction to the pitchblende veins and associated host shear zone. Pd values were found to range from 2 to 3 ppb; Pt was found to be <15 ppb in all cases. The Au content varies from 1 to 7 ppb. Although as much as 50 percent sulphide can occur in these veins over thicknesses of 2 to 4 cm, it is apparent from the assays that these sulphides are not enriched in precious metals.

Early Bird Showing

High-grade pitchblende mineralization and sulphide enriched mylonite was sampled at this locality. All Pd and Pt values obtained were below the detection limit. The Au values ranged from <1 to 126 ppb, averaging 49 ppb.

Rix Athabasca Uranium Mines Ltd. - Leonard Mine

Two contrasting types of geological environments were investigated at and near the Leonard mine:

1) A pyrrhotite- and pyrite-rich calcareous amphibolite unit near the Leonard mine was found to contain up to 40 percent sulphides. Textural features suggest that these sulphides are of synsedimentary origin. Pd, Pt and Au analyses of this material returned values of <2, <15 and 1 ppb respectively.

2) In contrast, a 4 cm thick pitchblende vein with minor amounts of sulphides gave very anomalous levels of 170 ppb Pd, 401 ppb Pt and 1975 ppb Au. Such anomalous levels suggest that further consideration should be given to the precious metal potential of this locality.

Uranium Ridge Mines Ltd. - Uranium Ridge Mine

Material from two different types of geological environment were sampled at this locality:

1) Uranium-vanadium ores from the mine were analyzed for Pd, Pt and Au. It was inferred that the uranium mineralization at this locality may be enriched in precious metals as at Nicholson and Fish Hook Bay. The latter localities are known to have anomalous levels of vanadium associated with the U-Au-PGE mineralized zones, unlike other deposits in the Greater Beaverlodge area. Also, there is a moderate statistical correlation between V, U, Pt, Pd, and Au at the Nicholson Bay (No. 2 zone) and Fish Hook Bay showings.

   Assays of the uranium-vanadium ores showed anomalous Pd, Pt and Au when compared with other uranium occurrences in the Greater Beaverlodge area (with the exception of the Nicholson and Fish Hook Bay properties). The average Pd and Pt values are 15 and 25 ppb respectively. The Au content ranges from 89 to 236 ppb. This is one of the very few occurrences where the Pt content exceeds that of Pd.

2) The pyritic graphite schist and meta-argillite country rock that host the vein-type pitchblende ores also contain anomalous levels of PGE and Au. The two samples analyzed returned 43 and 83 ppb Pd, 57 and 197 ppb Pt and 556 and 1018 ppb Au. As in the case of the uranium-vanadium ores, the Pt/Pd ratio is greater than one (1.3 to 2.4). These levels of precious metals, the attractive Pt/Pd ratio of the mineralization and the very reducing nature of these metasediments suggest a new and previously unrecognized precious metal environment which should be actively explored.

The graphitic meta-argillite and pyritic-graphite schist is structurally overlain by quartzite and is a distinctive sedimentary unit in the area southwest of Beaverlodge Lake. The Lorado Uranium mine, 1 km east-northeast of the Uranium Ridge mine, also occurs in a graphitic schist similar to that at the Uranium Ridge mine. Beck (1969, p.72) states that "On the footwall side of the main ore zone, a large mass of pyritized graphitic rock, as much as 30 m wide, was outlined by drilling for a strike length of 200 m and to a depth of three levels, with the limits undefined. For a time, the pyrite was mined to provide a source of elemental sulphur for acid production at the Lorado mill". Thus, it is clear that pyrite-graphite bodies (similar in composition to the precious metal enriched material sampled at the Uranium Ridge mine) of significant size exist within the meta-argillites southwest of Beaverlodge Lake and should be actively explored and assayed for their PGE and Au.

It is important to note that the new Au-PGE discovery of Lenora Explorations at "Quartzite Ridge" approximately 1.5 km southeast of the Lorado Uranium mine occurs in a similar suite of rocks. Channel samples cut across this brecciated hematized quartzite assayed 1.13 oz./ton Au, 0.047 oz./ton Pt and 0.088 oz./ton Pd (Whiteway, 1987).

It would be most informative to assay the quartzites that overlie the graphitic rocks at the Uranium Ridge mine and the Lorado Uranium mine, as well as any graphitic rocks in the vicinity of the mineralized quartzite in the Quartzite Ridge area. Both of these sedimentary environments could provide redox traps for hydrothermal fluids carrying precious metals.

Nicholson Bay - No. 2 Zone

Field and laboratory investigations on the Nicholson No. 2 zone mineralization continue. The recent availability of diamond-drill core from this zone has allowed new detailed investigations of the mineralized zone to be initiated. During the 1987 field season, diamond-drill core from this locality was sampled.

The most surprising observation from the core examinations and subsequent assay results was the cryptic nature of the precious metal mineralization. Samples were taken from the 28 m diamond-drill core cutting the Nicholson No. 2 zone hanging wall, footwall and pitchblende mineralization. Pd, Pt and Au assays reveal that the 1.5 m hanging wall interval averages 1201, 422 and >8057 ppb Pd, Pt and Au respectively. The average Pd, Pt and Au values for the 0.30 m thick pitchblende vein are 1540, 4222 and >10585 ppb. Significantly lower grades were encountered in the footwall sequence. The underlying 1 m interval in the footwall was found to average 99, 33 and 931 ppb respectively. The remaining 7.5 m footwall sequence averaged 84 ppb Pd and 121 ppb Au. How far anomalous levels of precious metals can be detected in the footwall sequence remains to be seen.

Significantly higher grades and widths have been encountered by Mary Ellen Resources within the Nicholson No. 2 zone. One of their diamond-drill holes cut 6.096 m of 8.67 ppm Pd, 2.05 ppm Pt and 18.2 ppm Au. The precious metals are restricted to a distinctive unit referred to as the "Red Zone", which consists of hematized carbonates and quartzites. The cryptic nature of the mineralization in the Red Zone and lack of accompanying sulphides, arsenides and pitchblende

(with the exception of the pitchblende vein) render this type of mineralization difficult to explore for and sample. Samples with assays as high as 1.2 oz./ton Pd, 0.20 oz./ton Pt and 11.5 oz./ton Au have been found in rocks with no macroscopic evidence of precious metals. The Mary Ellen Resources drilling program also revealed that the footwall sequence contains anomalous levels of gold, as was indicated above. In one case, the footwall was found to be anomalous over a thickness of 24 m.

Further major, trace, isotopic and fluid inclusion work will be conducted on the core from this zone in order to investigate the genesis of this new type of precious metal deposit.

Fish Hook Bay - Shirley Peninsula

Trenches and diamond-drill core from the mineralized zones on Shirley Peninsula were examined and sampled during 1987. Preliminary mineralogical investigations disclosed that some of the previously identified copper and lead selenides reported from this locality (Robinson, 1955) are actually a palladium selenide known as oosterbosschite. Oosterbosschite is an extremely rare platinum group mineral only known to occur in the Shinkolobwe uranium ores, Katanga Province, Zaire (Johan et al., 1970).

Heinrich (1958, p. 297) stressed the analogy of the selenium association with platinum group elements in the Shinkolobwe ores with those of the deposits in the Goldfields district of Saskatchewan. The uranium occurrences in the Greater Beaverlodge area have been classified as belonging to either the simple or complex mineralogical types (Robinson, 1955; Beck, 1969). The deposits of simple mineralogy consist of pitchblende accompanied by lesser amounts of chalcopyrite, pyrite and galena. Deposits of complex mineralogy consist of pitchblende accompanied by one or more of the following: Co-Ni arsenides and sulphides; Co-Ni-Pb selenides; and PGE, Ag and Cu in addition to the common accessory minerals found in deposits of simple mineralogy. Since the selenide association is restricted to the complex type, all such occurrences with the known presence of selenides (Robinson, 1955; Beck, 1969) should be explored for their precious metal content.

G.S.C. research has shown that selenium can be an important pathfinder for PGE+Au-enriched sulphides in the magmatic and possibly the sedimentary environment. This hypothesis has yet to be rigorously tested; however, values as high as 1.28 oz./ton Au were obtained in selenide-bearing pitchblende mineralization at locality 19A west of Lodge Bay.

Full PGE analyses conducted on high-grade samples from both the Nicholson and Fish Hook Bay mineralized zones reveal rhodium contents of 250 to 300 ppb. Such values are in excess of those noted for average Merensky Reef ore (Naldrett, 1981).

Other Uranium Deposits

At present research is in progress on the PGE+Au contents of the uranium deposits in the Athabasca Basin. To date three major deposits have been sampled and analyzed. None of these deposits has been found to contain greater than 90 ppb total PGE.

Athona Gold Mine

Sulphide-mineralized metagabbro and quartz veins from the Athona mine were sampled and analyzed for their Pd, Pt and Au contents. Mineralized metagabbro with 1 to 3 percent disseminated pyrite was found to contain <2 ppb Pd and <15 ppb Pt in all cases. Au values ranged from <1 ppb to 15 ppb.

Quartz veins within the metagabbro were also found to contain less than detection limit amounts of Pd and Pt; Au values exceeding 20,000 ppb were obtained from these same samples. Thus no significant PGE appear to be present in the Athona ores or host metagabbros.

Box Gold Mine

Ten mineralized samples from the Box gold mine were analyzed for Pd, Pt and Au. All samples assayed returned less than detection limit levels of Pd (2 ppb) and Pt (<15 ppb). Au values of >20,000 ppb were common in the analyzed samples. It can be concluded that the Box gold mine ores contain no significant quantities of Pd or Pt, contrary to information which suggested that old analyses found anomalous levels of Pd and Pt present in the ores.

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The Boundary Zone Between the Flin Flon Domain, Kisseynew Gneisses and Hanson Lake Block, Northern Saskatchewan

by K.E. Ashton[1], K.H. Wilcox[1], K.J. Wheatley[1], D. Paul[1] and J. de Tombe[1]

Ashton, K.E., Wilcox, K.H., Wheatley, K.J., Paul, D. and de Tombe, J. (1987): The boundary zone between the Flin Flon Domain, Kisseynew Gneisses and Hanson Lake Block, northern Saskatchewan; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

This report describes the results from the final field season of a four-year project directed towards gaining a better understanding of the southern flank of the Kisseynew Gneiss terrain. A preliminary geological map is included in the accompanying package. Earlier findings of this project are contained in Ashton and Wheatley (1985, 1986), Ashton et al. (1986) and Ashton (1987); the last-mentioned also includes a geological map.

The area studied this summer represents the boundary zone between the Flin Flon volcanic belt, Kisseynew Gneisses and the Hanson Lake Block.

Some previous workers considered the Kisseynew Gneisses to represent high-grade equivalents of the Flin Flon volcanic rocks (Wright and Stockwell, 1934; Byers and Dahlstrom, 1954; Ashton et al., 1986). The results of the present work are consistent with this theory and justify further the use of a common classification scheme for these rocks as suggested by Ashton et al. (1986).

General Geology

Amisk volcanic and volcaniclastic rocks on both sides of the boundary between the Flin Flon volcanic belt and the Kisseynew Gneiss Belt are similar to those observed elsewhere in the Kisseynew Gneisses (Ashton and Wheatley, 1986; Ashton et al., 1986). Intermediate to mafic compositions are represented by amphibolite and layered hornblende gneisses containing various amounts of garnet, clinopyroxene, biotite, cummingtonite/anthophyllite, carbonate and iron sulphides.

Felsic volcanic and volcaniclastic rocks tend to occur stratigraphically bounded by Amisk wackes and mafic volcanic and volcaniclastic rocks. The best-exposed occurrences consist of biotite-quartz-feldspar±hornblende±sillimanite rocks, which are gradational through rocks containing calcic amphibole and free carbonate, into mafic volcanic and volcaniclastic rocks. Cummingtonite/anthophyllite±garnet varieties are particularly common in the Wildnest-Schotts Lake region.

Most Amisk sedimentary rocks in the area studied are interlayered garnet-biotite±hornblende± graphite and hornblende-biotite gneisses, and represent a metamorphosed facies transition from the thinly bedded, magnetite- and amphibole-bearing wacke-argillite-slate-tuff sequence in the volcanic belt to the south, to the more homogeneous graphitic garnet-biotite±sillimanite wackes characteristic of the Kisseynew Gneisses to the east (Ashton, 1987). Garnet-andalusite and garnet-staurolite-sillimanite wackes, believed to be low-grade equivalents of the Kisseynew wackes, occur in the Flin Flon volcanic belt in the vicinity of Welsh Lake.

South of the boundary between the Flin Flon volcanic belt and Kisseynew Gneisses (Byers and Dahlstrom, 1954), Amisk felsic volcanic and volcaniclastic rocks and wackes contain abundant magnetite, in contrast to volcaniclastic rocks and wackes north of the boundary which are typically characterized by graphite. Magnetite persists in some northern felsic rocks, which may thereby be misidentified as Missi arenites. However, the presence of cummingtonite/anthophyllite±garnet assemblages in many of these rocks, and their gradation into more mafic volcanic units, is taken to indicate that they are part of the Amisk suite.

Although Missi rocks are not common in the area mapped, a sequence of polymictic conglomerates and overlying hornblende arenites was traced across the Kisseynew boundary from Amisk Lake to the east side of Granite Lake.

The Maskunow and Granite Lake hornblende granodiorites are also continuous across this boundary.

A suite of dioritic to gabbroic rocks, which locally contain coarse plagioclase phenocrysts and grade into gabbroic anorthosite, is tentatively correlated with the gabbro-diorite-granodiorite Neagle Lake Pluton (Pearson, 1951; Byers and Dahlstrom, 1954; Fox, 1976). The suite intrudes the Amisk Group, but its age relative to the hornblende granodiorites is not clear.

Structure

The regional structure has been previously outlined (Ashton and Wheatley, 1986; Ashton et al., 1986).

[1]Contracted project by the Geological Survey of Canada with funds provided under the Canada component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

The regional foliation is steep and generally strikes north in the Amisk Lake area, where early tight to isoclinal folding and associated layer-parallel shear zones are common. Asymmetric pull-aparts (Hanmer, 1984) and drag folding along the Annabel Lake Fault Zone (Byers and Dahlstrom, 1954), complemented by extension lineations at Welsh Lake and slickensides at Amisk Lake in the MacDonald Creek Fault system (Byers and Dahlstrom, 1954), consistently indicate oblique left lateral-reverse displacement along this set of shear zones in their present orientations (Wilcox, in prep.). These early structures have been folded, however, by a set of broad open east-northeast-plunging flexures. There is, in addition, a northward shallowing in the regional dip.

A ductile shear zone along the Sturgeon-Weir River overprints pre-existing structures and forms the boundary between the Flin Flon-Kisseynew terrain and the Hanson Lake Block. The zone consists of a locally porphyroclastic hornblende-bearing granodioritic gniess, which includes both supracrustal and intrusive components. Shearing has produced a variety of consistent kinematic indicators, including rotated winged feldspars (Hanmer, 1984), asymmetric pull-aparts (Hanmer, 1984), "c" and "s" fabrics (Berthé et al., 1979) and late drag folding which, together with a gently to moderately northeast-plunging extension lineation, indicate oblique right lateral-reverse shear (Wilcox and Ashton, in prep.). In addition to the structures mentioned above, sheath folds (Carreras et al., 1977), pseudotachylite and thin zones of mylonite were also observed. Late moderately southeast-plunging drag folds deform the shear fabric and extend at least as far as Granite Lake. Although an estimate of the magnitude of displacement would require a better knowledge of the geology of the Hanson Lake Block, the sense of offset as implied by the kinematic indicators is consistent with the suggestion that the Flin Flon-Kisseynew terrain is thrust over the Hanson Lake Block (MacQuarrie, 1979; Van Schmus et al., in press).

Late brittle faulting and cataclasis have affected an extensive area between the Sturgeon-Weir River and Granite Lake. This catalasis may be related in part to the Sturgeon-Weir Shear Zone, but the apparent left-lateral displacement along the fault through Granite Lake is consistent with that along the Ross Lake fault to the east (Byers et al., 1965) and the Tabbernor Lake fault set to the west (Macdonald and MacQuarrie, 1978).

Metamorphism

The metamorphic grade increases across all terrains from greenschist/amphibolite facies transition in the south, to upper amphibolite facies in the north and west. Garnet, andalusite, staurolite, kyanite and sillimanite have all been identified in wackes of appropriate composition between Amisk and Welsh Lake. J. de Tombe is presently conducting a study towards determining stability relations in the area.

Economic Geology

Disseminated iron sulphides are common throughout the Amisk volcanic and volcaniclastic rocks. More concentrated occurrences of iron and minor copper sulphides are found in Amisk wackes and volcaniclastic rocks along the south and east sides of Granite Lake.

A large occurrence of cordierite-anthophyllite-staurolite rocks was observed in Amisk wackes in the area southwest of Granite Lake, and is interpreted as the metamorphic equivalent of a chloritic alteration zone.

An extensive region of less altered felsic to intermediate volcanic and volcaniclastic rocks is marked by cummingtonite/anthophyllite±garnet rocks over much of the Wildnest Lake area. Previously noted examples occur at Schotts Lake (Pearson, 1986) and in the southern Wildnest Lake area (Ashton, 1987), but the affected region extends over most of Wildnest Lake. Carbonate-bearing volcanic and volcaniclastic rocks occur in a similar area and likely result from seawater or hydrothermal alteration prior to metamorphism.

Discussion

It has been suggested that the Kisseynew Gneisses represent the high-grade equivalent of the Flin Flon volcanic belt (Wright and Stockwell, 1934; Byers and Dahlstrom, 1954; Ashton et al., 1986), and that the Amisk-Missi classification scheme used in the low-grade rocks can be successfully applied to the gneisses further north (Ashton et al., 1986). Previous mapping demonstrated the gross similarity of lithologies and age relationships across the boundary (Ashton et al., 1986), but the inability to conclusively demonstrate the continuity of units from the Flin Flon volcanic belt into the Kisseynew Gneisses, and the apparent coincidental facies change in the Amisk Group from dominantly volcanic to dominantly sedimentary, left the correlation in some doubt. This objection is no longer valid, however, since rocks of both the Amisk and Missi Groups have now been traced continuously from the Amisk-Johnson Lake area of the Flin Flon volcanic belt into the Kisseynew Gneisses at Granite Lake, providing further evidence that the boundary between the two terrains in Saskatchewan represents a change in metamorphic grade and structural style only, and not a distinct stratigraphic break. It also provides further justification for discontinuing the Nokomis-Sherridon classification of the Kisseynew Gneisses (Robertson, 1953) in favour of the Amisk-Missi scheme, as has been previously suggested (Ashton et al., 1986).

Conclusions

Amisk and Missi Group rocks of the Flin Flon volcanic belt have been traced continuously from the Amisk-Johnson Lake area into the Kisseynew Gneisses in the vicinity of Granite Lake. Most Amisk sedimentary rocks within the Kisseynew terrain are interlayered garnet-biotite±graphite and hornblende-biotite±garnet wackes and tuffs, and are thought to represent a facies transition between the Amisk wacke-argillite-tuff sequence of the Flin Flon volcanic belt and graphitic garnet-biotite± sillimanite wackes mapped as part of the Nokomis Group (Robertson, 1953) to the northeast.

Early structures include tight to isoclinal folds and associated shear zones which exhibit evidence of oblique left lateral-reverse displacement in their present orientation. Following the development of a set of broad, open northeast-plunging flexures, the Flin Flon-Kisseynew terrain was thrust southwestward over the Hanson Lake Block along the Sturgeon-Weir Shear Zone. Brittle fracturing subsequently affected an extensive area between Granite Lake and the Sturgeon-Weir River, and resulted in the apparent left-lateral fault along Granite Lake.

The first appearance of garnet, andalusite, staurolite, kyanite and sillimanite, associated with increasing metamorphic grade, occurs between Amisk and Welsh Lakes. Elsewhere, stable assemblages are consistent with metamorphism in the middle to upper amphibolite facies.

An outcrop of cordierite-anthophyllite-staurolite rocks was observed in the southwest of the Granite Lake area. Cummingtonite/anthophyllite±garnet and carbonate-bearing volcanic and volcaniclastic rocks occur extensively in the vicinity of Wildnest Lake, and are interpreted as metamorphic equivalents of hydrothermally altered rocks.

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OTHER NORTHERN STUDIES

Precious Metals in Vegetation from Northern Saskatchewan, 1987

by Colin E. Dunn[1]

Dunn, C.E. (1987): Precious metals in vegetation from northern Saskatchewan, 1987; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

Studies have continued this year on the distribution of precious metals in and among common plant species of the northern forests.

The field component of the work comprised three days in the Rottenstone area. Other information reported here is derived from material collected by the author in 1986, and a few samples of interest collected by Antelope Oil and Gas this year.

Platinum

Rottenstone Lake

The Rottenstone area ("Hall" showing, Ni, Cu, and Pt mineralization in an ultramafic matrix) was first selected for the study of platinum-group metal (PGM) uptake by vegetation in 1983 (Dunn, 1983, 1986a), and has proved to be a valuable field laboratory for examining patterns of precious metal distribution in many of the common plants that comprise the boreal forest. Twigs of black spruce were found to accumulate PGMs to higher concentrations than other plant parts (up to 1,350 ppb Pd and 880 ppb Pt in ash). This year further research on this material and additional bulk samples collected in 1984 and 1986 have revealed certain analytical problems, as well as provided the first data on the full suite of PGMs in vegetation (Dunn et al., in press). Table 1 summarizes these data, which were obtained by neutron activation analysis (NAA) following a nickel sulphide fire-assay of ash samples weighing from 5 to 10 g.

Iridium is the only PGM which can be readily detected by the rapid instrumental neutron activation method (INAA) commonly employed for multi-element analysis. Iridium, although of very low cosmic abundance, can be detected by routine INAA at levels as low as 0.2 ppb Ir in 8 g pellets of dry vegetation, and as low as 2 ppb in 1 g of plant ash. Lower levels of detection are possible by performing a longer counting procedure. Background levels of Ir in vegetation are only a few parts per trillion but, in the vicinity of PGM mineralization, Ir levels may be elevated to above the INAA detection limits. As a result of these factors, and in view of its geochemical associations, iridium may be considered a pathfinder element since any detectable Ir in vegetation would suggest the presence of elevated concentrations of platinum in bedrock.

Preliminary data from wet chemical analysis of ashed samples from Rottenstone show that the order of Pt abundance is (from highest to lowest): black spruce twigs > black spruce bark > labrador tea twigs > alder leaves > black spruce trunkwood = jack pine trunkwood > jack pine twigs > alder twigs > horsetail > jack pine needles > black spruce

[1]Exploration Geochemistry Subdivision, Mineral Resources Division, Geological Survey of Canada.

Table 1 - Platinum Group Metals and Gold in Single Samples of Ashed Vegetation from the Vicinity of the Rottenstone (Hall) Ni-Cu-PGM Deposit, Saskatchewan. Data obtained by NAA following NiS fire assay. All precious metal values in ppb.

Common Name	Botanical Name	% Ash	Pt	Pd	Os	Ir	Ru	Rh	Au
Spruce Twigs A	Picea Mariana	2.84	830	1100	28	24	30	34	101
Spruce Twigs B	Picea Mariana	2.76	910	410	13	15	21	49	100
Spruce Twigs C	Picea Mariana	1.77	110	<100[1]	7	4.4	15	9	20
Spruce Trunkwood	Picea Mariana	0.70	300	270	10	5.6	12	9	28
Alder Twigs	Alnus Crispa	1.46	100	65	3	1.7	8	6	28
Alder Leaves	Alnus Crispa	3.83	420	490	15	9.8	37	26	110

[1]high detection limit due to small sample weight.

needles > birch twigs > willow twigs > labrador tea leaves > grass.

At the end of June 1987, a small-scale biogeochemical survey was conducted "down-ice" from the Hall deposit, in conjunction with a bulk till geochemistry sampling program by J. Campbell (Saskatchewan Research Council) and W. Coker (Geological Survey of Canada). The purpose of this study is to assess the relative value of the two procedures in defining down-ice dispersion trains of precious metals from the Hall deposit. Results are pending.

Tremblay Lake

Fifteen kilometres northeast of Rottenstone Lake there is a diabase dyke with some enrichment of PGM (>100 ppb, L. Hulbert, pers. comm.). Part of this dyke forms a densely wooded island in Tremblay Lake. A brief biogeochemical survey of the west part of this island was conducted in June 1986. One sample of ashed black spruce bark yielded 31 ppb Pt and 10 ppb Pt in twigs of the same tree. Labrador tea twigs a few hundred metres distant yielded 77 ppb Pt (Dunn et al., in press). The inference is that, in areas of thin overburden, the vegetation may be used as a preliminary screening tool for detecting bedrock enrichment of PGM in the order of a few hundred ppb.

Gold

Koliniak Lake

Phenomenal concentrations of gold have been found in ashed vegetation from near Koliniak Lake, 12 km east-northeast of Lower Waddy Lake. This area of high-grade felsic to intermediate gneisses with intercalated basic volcanics was mapped in detail by Johnston (1969), who reported gossans and some enrichment of base metals in soils and bedrock. A few samples of alder and pine twigs were collected by A. Frew (for Antelope Oil and Gas) in June 1987 from topographic hollows near disseminated pyrite and pyrrhotite occurrences, as part of a broad geochemical reconnaissance of areas of gold potential.

Combined samples of alder twigs and leaves were ashed at 600°C[1] and analyzed for gold by conventional lead fire assay cupellation, followed by solution in aqua regia. This work was conducted by Loring Laboratories, Calgary, exercising care to avoid contamination. Concentrations (over 130,000 ppb Au) were so extreme that they were worthy of more detailed investigation, as well as comparison with the large database of similar material currently being compiled at the Geological Survey of Canada (GSC).

[1]At this temperature most of the Cs and Rb will volatilize.

Ashed samples weighing about 0.5 g were loaded into vials at the GSC and analyzed by INAA at Activation Laboratories Ltd., Brantford, Ontario.

Gold concentrations from these samples yielded from 130 to 231,000 ppb Au (equivalent to almost 5,000 ppb Au in dry material); this is higher than any previously recorded gold concentration in vegetation, except for a report by Babicka (1943) which was later shown to be false (c.f., Brooks, 1982). The only concentration recorded of similar magnitude was 180,000 ppb Au in ashed pine twigs from Tasmania (Baker, 1986). Of particular interest is the coincident enrichment in the vegetation of anomalous concentrations of several elements commonly associated with gold mineralization (Table 2).

Table 2 - Elements in Ashed Alder and Leaf Samples (Combined) from near Koliniak Lake (n=12; ash yield approximately 2 percent).

	Koliniak Lake	Normal Background (approx.)
Au	130-213,000	10-20
Ag	31-380	<5
As	<2-370	1
Br	11-600	40
Co	8-62	10
Zn	3,000-8,200	1,000

Au in ppb, all other elements in ppm

It was noted earlier that bromine is enriched in alder ash near some zones of gold mineralization (Dunn, 1985). Six of the samples analyzed contained over 300 ppm Br. Cobalt was slightly enriched in several samples; antimony and molybdenum were significantly enriched in one sample. In addition to the trace element data, major element analyses indicate significant sodium enrichment, moderate iron enrichment and possibly slight potassium depletion.

This assemblage of elements is remarkably consistent with those commonly associated with certain styles of gold mineralization. Whereas gold mineralization has not as yet been uncovered in this area, the biogeochemical data indicate that the area warrants closer investigation in order to establish the reasons for such extreme enrichments in the vegetation.

Integrated Study of the Star Lake Area - An Update

Biogeochemistry

In 1986 a study was launched in an attempt to integrate biogeochemical data with remotely sensed

data, known mineralization and bedrock geology (Dunn et al., 1986). To date, multi-element data have been compiled for ashed spruce bark and alder twigs obtained from about 600 sites within a 150 km^2 area encompassing the Star Lake gold mine, the Rod Zone and the newly discovered Transom Lake/Jasper mineralization (Fig. 1). Spruce bark information has been summarized earlier (Dunn, 1986b), since which time the alder samples have been analyzed. The significant new information to emerge from the alder study is that many samples collected near the eastern edge of the Island Lake Pluton and into the pluton (near the old 'Decade Mine' trail, 1 to 2 km west of Pesimokan Lake) have yielded anomalous concentrations of gold (10 times background) and molybdenum (100 times background). This zone of anomalies is "up-ice" from the Jasper showing, suggesting additional zones of mineralization to the northeast.

Throughout the study area, there is a broad coincidence of cesium enrichment associated with elevated concentrations of gold in the vegetation. Cesium is a rare element which forms few minerals, one of which is galkhaite. This extremely rare mineral has been found in association with the Hemlo gold deposits (Harris, 1986). Although the cesium enrichment may not in itself be highly significant, the association with gold is further encouragement that mineralization may be present.

Data Integration

Spectral reflectance data from four flights over part of the area are currently being processed. Details of the multi-detector electro-optical imaging scanner system (MEIS) used are given in Dunn et al. (1986).

Landsat (TM) data tapes have been received and registered, and data analysis will commence in the near future.

Within the past month a new spatial data analysis (TYDAC) system has been obtained at the GSC, and a post-doctoral fellow will establish procedures required to integrate the data sets, including the newly acquired stable base geology maps from the field programs of Thomas (1984, 1985) and Harper (1986), high resolution gamma-ray spectrometry surveys (Geological Survey of Canada, 1987) and aeromagnetic data.

It is hoped that this exercise will help to refine exploration targets, and assist in the discovery of more zones of mineralization.

Acknowledgements

I thank D. Surjik (Antelope Oil and Gas) and A. Frew for supplying the samples from the Koliniak Lake area and permitting release of the data.

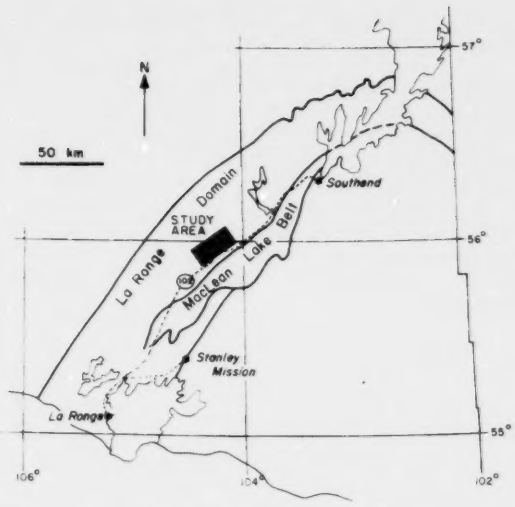

Figure 1 - Location of the Star Lake study area.

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Geology and Geochemistry of the Bassett Lake Complex: Progress Report

by Ian Graham[1], B.R. Watters[1] and Larry Hulbert[2]

Graham, I., Watters, B.R. and Hulbert, L. (1987): Geology and geochemistry of the Bassett Lake Complex: progress report; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

The Bassett Lake Complex is situated in the vicinity of Bassett Lake in the central Metavolcanic Belt, La Ronge Domain, approximately 14 km west-southwest of Otter Rapids (Fig. 1). The complex comprises a suite of layered mafic to intermediate rocks which outcrop over an area of approximately 12 km^2. Primary magnetite mineralization produces an associated regional aeromagnetic anomaly (Geological Survey of Canada, 1966). Ground electromagnetic and magnetic surveys have defined significant anomalies centred in the Triangle Lake[3] area and along the west and northwest shores of Bassett Lake (Dunlop, 1968).

Previous Work

Previous work on the intrusion, including regional bedrock mapping by McLarty (1936a, 1936b) and Padgham (1960), airborne electromagnetic surveys (Stemp, 1965; Geological Survey of Canada, 1966) and a ground electromagnetic survey (Dunlop, 1968), has been summarized by Harper (1983) and Graham et al. (1986). Trenching was undertaken at the Triangle Lake sulphide showings in 1957 and 1961. Richards (1964) described pyrrhotite and pyrite mineralization in gabbroic core from five localities, and Reynolds (1967) reported significant pyroxenite in a predominantly dioritic body. An assessment of the magnetite-rich area for potential iron ores was made by Harper (1983).

Present Project

Detailed mapping and sampling of the Bassett Lake Complex has been completed and preliminary results, including a geological map, presented (Graham et al., 1986). Geochemical, petrogenetic and mineralization studies are currently in progress. Sulphide-rich cumulus magnetite layers associated with the gabbroic rocks have been examined for gold and platinum group elements (PGE) by Hulbert (1986). Preliminary analyses of samples indicated Pd, Pt and Au values below the detection limits of 2, 15 and 1 ppb, respectively. More recent analyses have shown the following maximum values: 13 ppb Ru, 2 ppb Rh, 23 ppb Pd, 47 ppb Pd, <3 ppb Os and 45 ppd Au (Table 1).

Mineralogy, mineral zoning and cryptic layering of silicate phases in core samples were investigated by electron probe micro-analysis, and a preliminary whole rock geochemical study has also been carried out.

Table 1 - Platinum Group Element and Gold Assays on Samples from the Main Sulphide Showings at Triangle Lake and from a Sample of Highly Sheared Rock along the Western Margin of the Body (1-153). Values in ppb.

Sample No.	Ru	Rh	Pd	Pt	Au
1-199	<5	<1	8	20	5
1-219	<5	<1	11	35	14
1-193	<5	6	21	44	15
1-153	<5	1	-	19	2
1-189	13	2	23	47	45

Geology

Regional Setting

The Bassett Lake Complex is thought to have been emplaced into Early Proterozoic volcanic rocks of the Central Metavolcanic Belt, La Ronge Domain prior to a period of major Hudsonian plutonism. A compositionally variable granodioritic pluton lies in contact with the complex in the northwest, in part along a minor shear en echelon with a major north-trending shear zone (Graham et al., 1986).

A biotite diorite to quartz diorite body, the Beranek Lake Pluton (Thomas, this volume), lies on the eastern flank. A smaller, more felsic and hornblendic, intrusion has recently been recognized along the eastern contact zone. This stock, previously considered a contiguous variant of the Beranek Lake Pluton (Fig. 1), is now termed the Hood Creek Intrusion (Thomas, this volume).

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[3]unofficial name.
Project supported under the Canada component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89, with logistic support from the Saskatchewan Geological Survey.

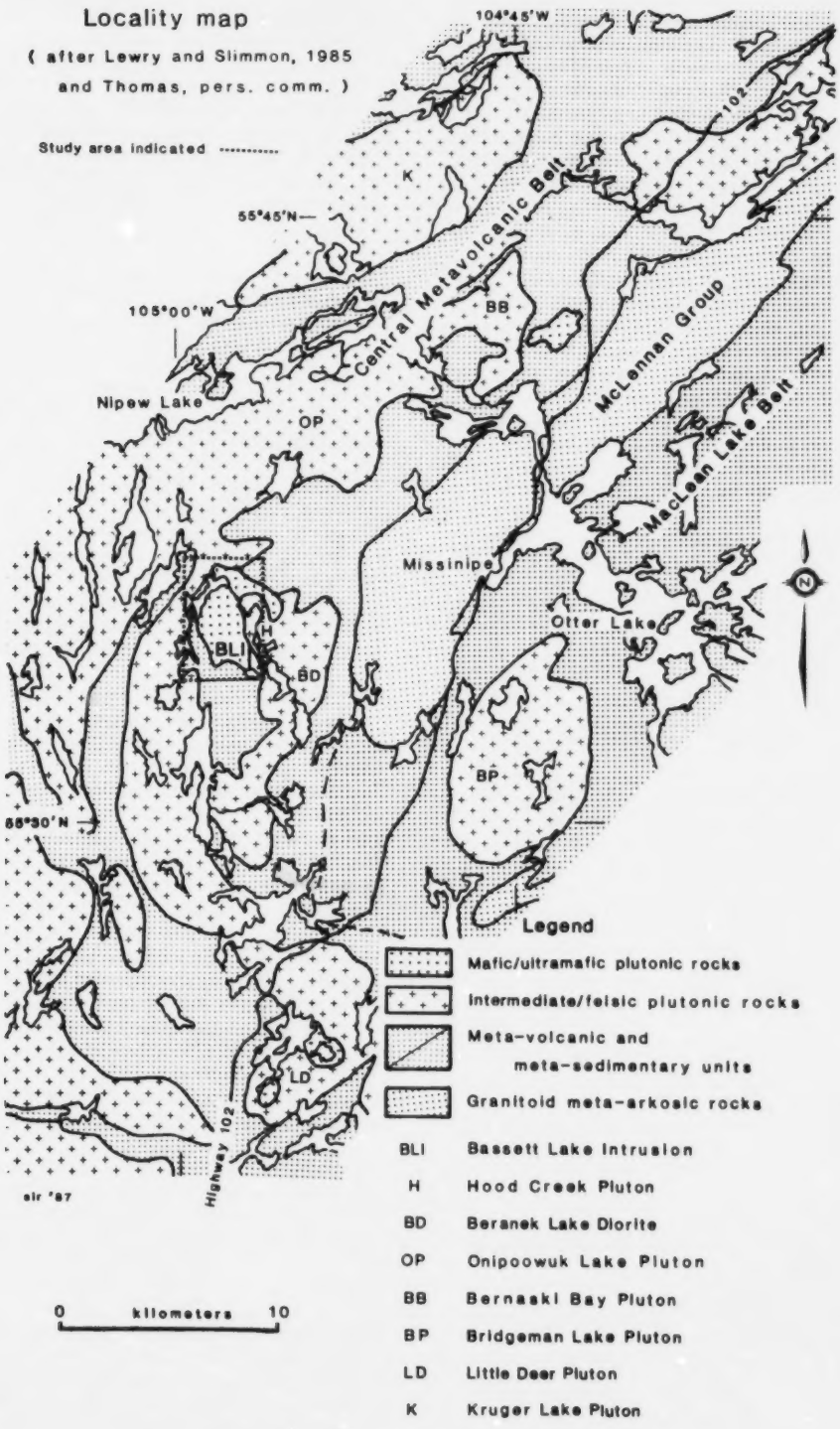

Figure 1 - Location of the study area in the southern part of the Central Metavolcanic Belt, La Ronge Domain.

Lithologic Zonation

Two broadly defined zones are recognized in the Bassett Lake Complex. The core zone is composed of well-layered, predominantly magnetite-bearing rocks and includes the ultramafic lithologies described from the area. Massive sulphide mineralization is restricted to this core zone, which is centred on Triangle Lake and extends northward along the west and northwest shores of Bassett Lake (Graham et al., 1986). The lithologies described from drillhole B1 core (Fig. 2) are typical of the core zone. Well-developed phase and textural layering occurs on a centimetre to metre scale, though little lateral continuity was observed.

The outer zone comprises predominantly gabbroic to dioritic rocks (Graham et al., 1986). Monzonitic rocks outcrop in the south of the zone. Crude metre-scale layering is commonly developed in the variably foliated and more widespread gabbroic rocks, which also occur locally as massive to weakly foliated outcrops with no visible layering. Variable amounts of hornblende are present, usually as large poikilitic crystals, and areas of "anorthositic" gabbro occur widely.

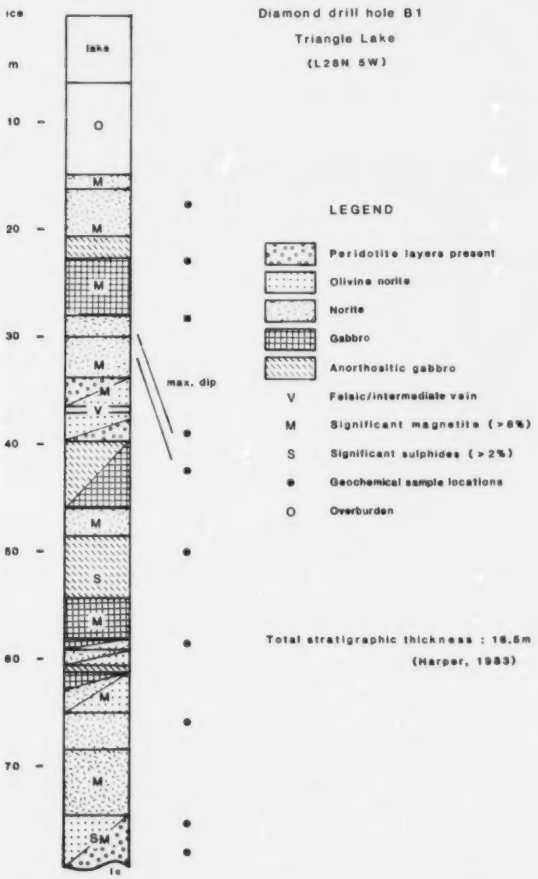

Figure 2 - Schematic log of rock types in core from diamond-drill hole B-1, Triangle Lake. Included for the localities of core samples for initial geochemistry.

A large part of the western contact zone is affected by veining associated with the later plutons (Graham et al., 1986), which defines a contaiminated zone affecting both core and outer zone lithologies. Geochemical studies are in progress to determine the extent of trace element contamination resulting from this veining (see "Preliminary Geochemistry" section).

Outcrops of veined, angular, blocky "breccia" occurring along the eastern contact zone have been interpreted as possible intrusion breccia (Graham et al., 1986). Boundaries between the core and outer zones of the Bassett Lake Complex are gradational.

Core Zone Lithologies

The main lithologies of the core zone have previously been described (Graham et al., 1986). These rocks include gabbro, norite, hyperite, peridotite, anorthosite and magnetite-rich varieties of these rock types. Massive sulphide and oxide zones are apparent in outcrop and diamond-drill core. A synopsis of the previous report and some recent observations are presented here.

Gabbroic Rocks - The gabbroic rocks in the core zone include gabbro, norite, hyperite and their magnetite-rich equivalents. The gabbro contains ferroan augite (diallage) and predominantly actinolitic "uralite". Hypersthene in the noritic rocks is commonly oikocrystic, producing "lustre mottled" outcrop surfaces. Finer grained saccharoidal-textured varieties of norite contain hypidiomorphic to allotriomorphic orthopyroxene.

Hyperite (a noritic rock containing subequal amounts of orthopyroxene and clinopyroxene) has been recognized in thin section and displays most of the features of the more common norite. Both rock types have green hornblendic reaction rims mantling clinopyroxene. A colourless fibrous corona is commonly associated with the orthopyroxene.

Plagioclase in the gabbroic rocks ranges in composition from sodic bytownite to andesine. Laths are commonly subhedral and zoning is predominantly of normal type. Red-brown titaniferous biotite and accessory apatite are present.

Magnetite-rich gabbroic rocks are distinguished from "normal" types by the modal proportion of oxides. "Normal" gabbro and norite contain less than 8 to 10 percent magnetite; magnetite-rich gabbro and norite contain up to 30 percent opaque minerals. These proportions are revised from Graham et al. (1986).

The magnetite-rich gabbroic rocks are melanocratic and display granular, anhedral and subhedral textures, except where individual crystals are enclosed by magnetite and euhedral crystals are developed. The magnetite occurs as an intercumulous phase.

Ultramafic Rocks - Ultramafic rocks containing variable amounts of magnetite occur as layered units in the core zone of the intrusion. No significant occurrences of pyroxenite were observed, although Reynolds (1967) reported extensive development of such rocks. True pyroxenites are rare among the layered rocks, as plagioclase usually constitutes more than 10 percent of the rocks. Harper (1983) reported a minor development of peridotite in a sample taken from Triangle Lake diamond-drill core. Although no extensive peridotite layers have been recognized in the present study, the silicate mineral asemblage present in the magnetite-rich layers is commonly that of peridotite, or olivine pyroxenite (wehrlite). One very thin layer composed predominantly of olivine and oligoclase/labradorite has been identified as a troctolite.

Highly Magnetic Rocks - Magnetite-rich layers (with magnetite content greater than 50 percent) occur in the core zone. These rocks have been mapped as magnetitites, and are responsible for the high local magnetic anomalies recorded in a ground electromagnetic survey (Dunlop, 1968). Geochemical analysis of these rocks is incomplete, but the highest FeO value recorded among the samples analyzed to date is 41 percent. A true magnetitite should contain at least 65 percent Fe (Bates and Jackson, 1987).

A thin section from drillhole B1 core (Fig. 2) contains approximately 60 percent opaque minerals (predominantly magnetite), 20 percent olivine (including such alteration products as iddingsite and antigorite), augite and minor plagioclase. The silicate mineral composition of the rock designates it as a peridotite. The rock displays a sideronitic texture as the silicate phases occur as "blunt subhedral to euhedral crystals enclosed in a matrix of magnetite" (Moorhouse, 1959, p.319).

Among the highly magnetic rocks are several fairly extensive occurrences of "massive" sulphides and oxides. Sulphides constitute up to 50 percent of the rock and include pyrrhotite, pentlandite, some bornite and minor chalcopyrite. The silicates present include plagioclase, orthopyroxene, clinopyroxene and olivine. Plagioclase and pyroxene are the dominant silicate phases in a large proportion of these rocks. Olivine-rich rocks with high sulphide content generally contain pyroxene but very little plagioclase. Reaction rims commonly mantle silicate minerals where they are in contact with sulphides and oxides.

Anorthositic Rocks - Anorthosite occurs in most parts of the core zone. This rock contains as little as 5 percent mafic minerals, mainly hornblende in the coarser grained varieties. Fine-grained anorthosite occurs in association with the layered noritic and magnetite-rich noritic rocks. In this variety, the major mafic mineral is fine-grained hypersthene (5 to 10 percent) which occurs among cumulus feldspars. Magnetite-rich anorthosite (10 to 15 percent magnetite) occurs at several localities.

Outer Zone Lithologies

The outer zone rock types include gabbro, hornblende gabbro, anorthositic gabbro, diorite, monzonite and some xenoliths of the metavolcanic country rock. Some magnetite-rich varieties show well-developed layering.

Hornblende occurs in variable amounts in the gabbroic and dioritic rocks of the outer zone, usually as large poikilitic crystals. Deuteric alteration of the mafic phases to uralite is also variable, although some secondary amphibole may be due to regional thermotectonism. The effects of regional metamorphism on the Bassett Lake Intrusion have been slight, so primary mineralogical features and igneous textures are generally well preserved. Some sharply bounded leucocratic veins as well as irregularly distributed massive leucocratic rocks occurring in this zone represent late phases of the mafic complex.

Mafic intrusive sheets are associated with mesocratic monzonitic rocks in the south of the outer zone. These sheets may be a result of magmatic events postdating the Bassett Lake Complex, or may be coeval with the core zone rocks, suggesting a possible multiple injection history for the intrusion.

Regional Structure

A north-trending major zone of mylonitization, over 50 m wide in places, is well developed in the grandiorite on the western side of the complex. This shear zone extends northward through Beaudry and Fault Line Lakes (Thomas, pers. comm.) and southward through Thornton Lake.

Preliminary Geochemistry

Initial analyses for platinum group elements have indicated no appreciable quantities of these elements in the Bassett Lake mafic rocks or in mineralized samples of the immediately adjacent metavolcanic rocks (Table 1).

Previous geochemical work in the region was carried out by Harper (1983), using rock chip samples from the sulphide- and oxide-rich

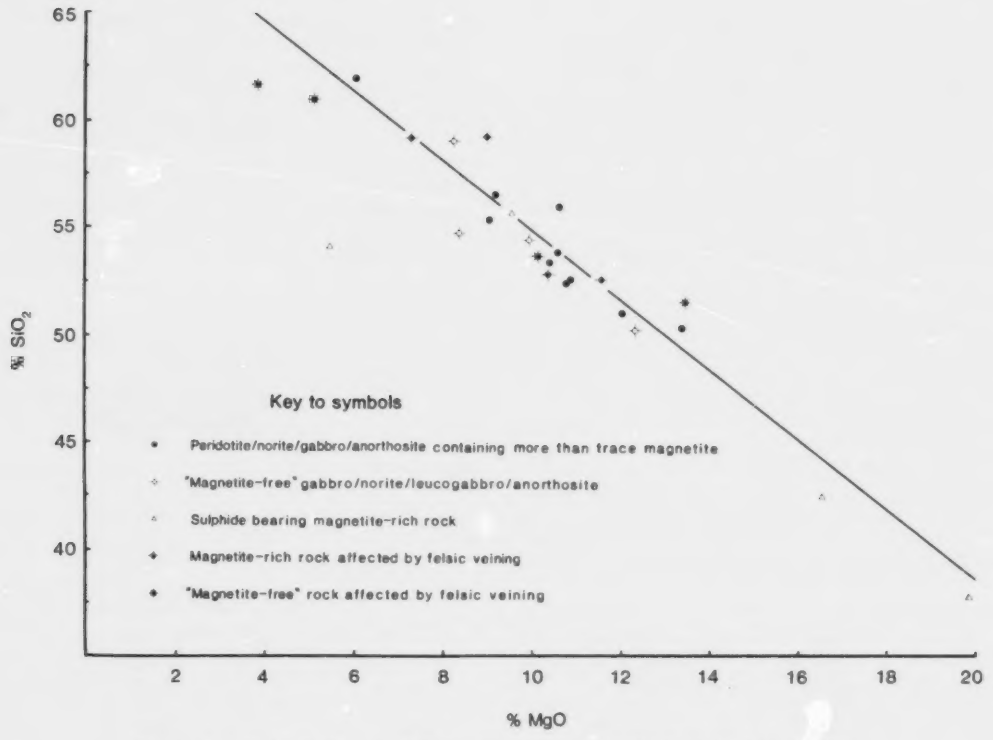

Figure 3 - Plot of SiO_2 vs. MgO for 28 samples from the Bassett Lake Complex.

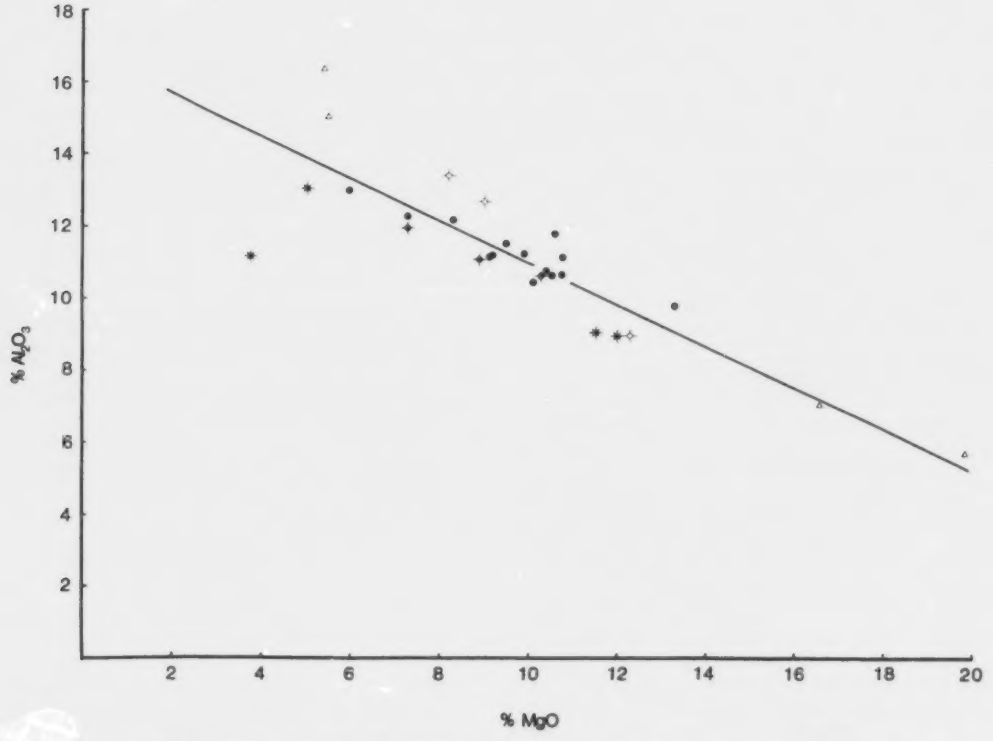

Figure 4 - Plot of Al_2O_3 vs. MgO for 28 samples from the Bassett Lake Complex. Symbols as for Fig. 3.

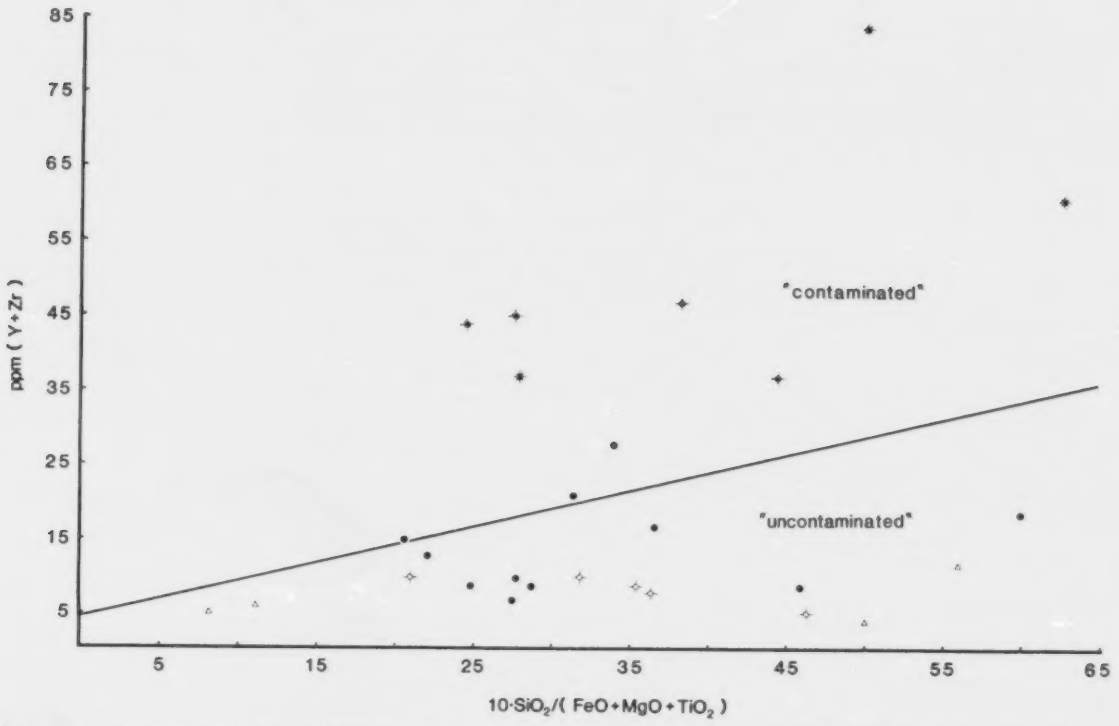

Figure 5 - Plot of (Y + Zr) vs. an index of mafic and oxide content used to identify contamination of Bassett Lake units by veins related to later felsic plutons. Symbols as for Fig. 3.

mineralized zones. Harper's samples were each representative of a 3 m section, and showed mineralized sections to average about 2 percent Ti. The titanium occurs in ilmenite exsolution lamellae in magnetite and titanomagnetite.

A preliminary suite of 28 samples from the Bassett Lake Complex, including ten samples from drillhole B1 core, have been analyzed for major elements and some trace elements. Results indicate a maximum total iron content of 40.4 percent (as FeO) in a core sample from drillhole B1. Ferrous iron makes up an average of 69.57 percent (maximum 88 percent, minimum 59 percent) of the total iron content of fourteen surface samples.

Major element and some trace element data are displayed on Harker variation diagrams (Figs. 3, 4 and 5). Element concentration data obtained from diamond-drill core samples have been plotted against depth. The rock types sampled for these analyses are indicated in Fig. 2.

A relatively linear decrease in MgO with increase in silica is indicated in Fig. 3. Although this is a common geochemical feature of mafic igneous suites, it is significant in the Bassett Lake occurrence as it suggests that silica-magnesia fractionation is independant of magnetite development.

A similar pattern to that of Fig. 3 exists in a plot of Al_2O_3 versus MgO (Fig. 4), where a decrease in alumina with increasing magnesia is observed. This trend reflects the decrease in plagioclase with increasing content of ferromagnesian minerals. It may also indicate a decrease in alumina among the mafic minerals, thereby refecting a change in the predominant pyroxene species from Al-bearing augite to Mg-rich orthopyroxene.

The trace elements yttrium and zirconium (as Y + Zr) are plotted against a factor used as an index of decreasing mafic and oxide phases in Fig. 5. Those mafic samples collected adjacent to veins associated with the later plutonic activity show an enrichment in (Y + Zr), probably as a result of contamination by the veins. The "contaminated" and "uncontaminated" fields are separated in the figure by an arbitrary reference line.

Plots of elemental concentration versus depth are presented in Fig. 6 and 7. An inverse relationship between SiO_2 and MgO concentrations is present, and a sharp increase in silica in the lowest reaches of the drillhole coincides with a highly mineralized sulphide and oxide zone.

Fig. 7 shows a similar pattern for total iron (as weight percent FeO) and total alkalis ($Na_2O + K_2O$) versus depth. The FeO trend reflects the relative

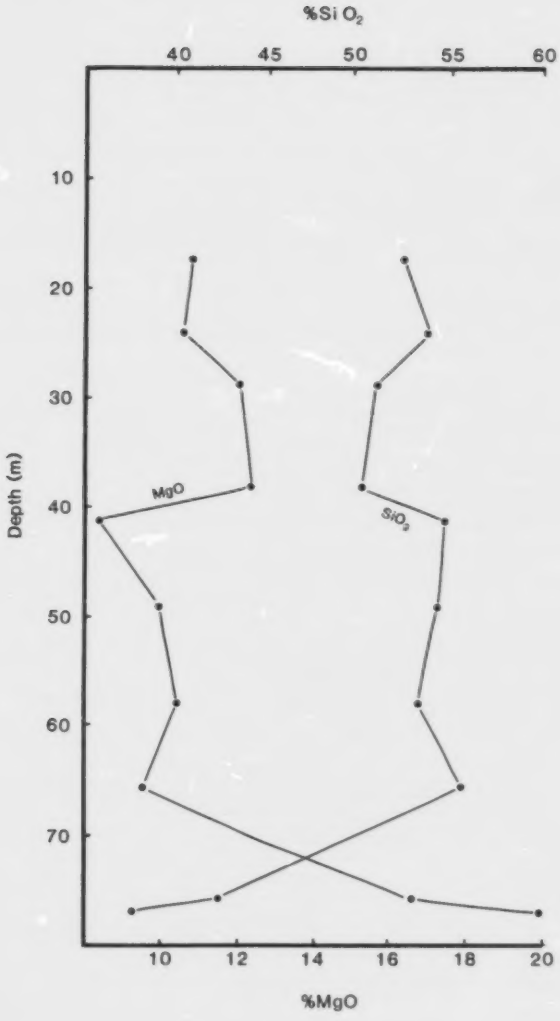

Figure 6 - Trace of the variation in MgO and SiO_2 concentrations with depth in drillhole B1.

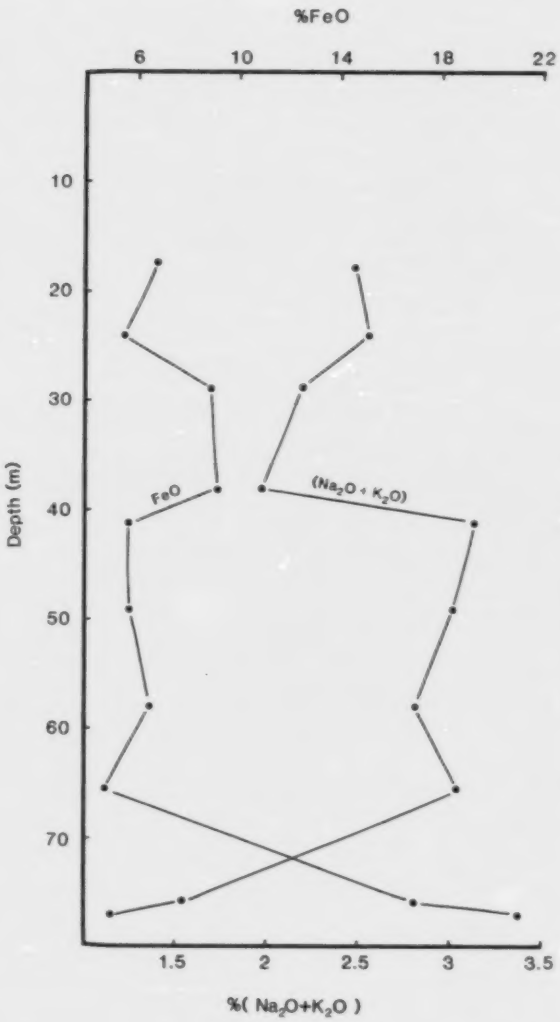

Figure 7 - Trace of the variation in total alkalis (Na_2O + K_2O) and total iron (as FeO) with depth in drillhole B1.

abundance of mafic and oxide phases in the core samples. The inverse pattern in the alkalis suggests that very little remobilization of these elements has occurred between the various layers in the Triangle Lake area.

Summary

The Bassett Lake Complex is intrusive into predominantly metavolcanic rocks of the Central Metavolcanic Belt, La Ronge Domain and is bounded to the east and northwest by later granodioritic and dioritic plutons. The complex comprises a suite of gabbroic rocks with ultramafic units developed in a layered core zone, and dioritic rocks developed in an outer zone.

Magmatic magnetite is variously developed, producing areas of anomalous positive magnetic intensity. Mild deuteric alteration affects much of the intrusion and a graphic granitic veining is commonly developed.

Preliminary geochemical results indicate possible contamination in rocks affected by post Bassett Lake veining. These geochemical data may help in determining the level of contamination in samples from outcrops where veining was not observed.

Acknowledgements

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Quaternary Geology of the East Amisk Lake Area, Applied to Prospecting for Gold

by Janet E. Campbell[1]

Campbell, J.E. (1987): Quaternary geology of the East Amisk Lake area, applied to prospecting for gold; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

The Saskatchewan Research Council is documenting Quaternary geology in the East Amisk Lake area, including the type, distribution and stratigraphy of deposits, the source of materials, and the direction and distance of transport. This information is used to determine the most useful sampling media and the most effective techniques for drift prospecting.

The 210 km^2 study area covers the region from Creighton south to the limit of the Precambrian Shield and from the Manitoba border west to Amisk Lake (Fig. 1). The area was chosen for its known gold deposits and showings, and for the complexity of the Quaternary geology which includes the influence of Lake Agassiz. Preliminary maps of the Quaternary geology are included in the accompanying package. A final report to be published by the SRC will be similar in scope to previous reports on the Waddy Lake (Campbell, 1986) and Sulphide - Hebden Lakes (Campbell, 1987) areas.

Procedure

Airphoto interpretation of the surficial geology was completed prior to the field mapping, which was carried out at 1:20,000 scale. Ground-checking was carried out at 218 sites. Hand-augered holes or small pits were dug to an average depth of 0.8 m at most of these sites.

Subsurface stratigraphic information was obtained by drilling eleven roto-sonic holes along Highway 167 and the West Arm Mine road at depths ranging from 2 to 11.6 m. It is assumed that the holes terminated at bedrock, although this is not certain as the roto-sonic drill cannot discriminate bedrock from very large boulders. Basal till was encountered in six of the eleven holes.

Surface samples representative of the various deposits were collected; however, the main emphasis was on sampling till from the C-horizon. Seventy-five bulk till samples (6 to 10 kg), including nine from the drillholes, were collected in all. The up-ice side of ridges and outcrops was the preferred surface sampling site.

[1]Resources Division, Saskatchewan Research Council, Saskatoon.

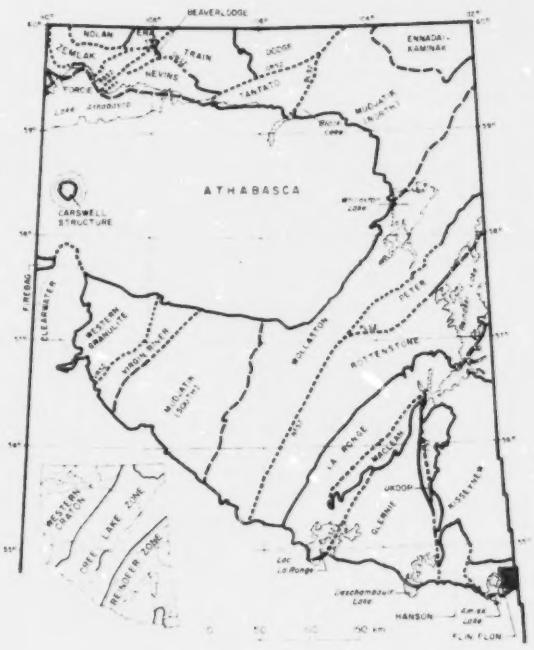

Figure 1 - Location of the study area.

General Geology

Drift cover in the area is thin and discontinuous in comparison to the La Ronge Belt (Campbell, 1986, 1987) with the exception of the south, where bedrock relief is lower. The approximate areal proportions of surface materials are: 40 percent bedrock, 25 to 30 percent glacial till, 15 to 20 percent glaciolacustrine, 10 to 15 percent organic and less than 5 percent glaciofluvial. Based on the roto-sonic drillholes and mineral exploration wacker drilling programs, drift thickness is highly variable. Although 11.6 m is the deepest hole drilled during this study, depths greater than 21.5 m have been recorded in topographic lows tested by wacker drilling (M. Koziol, pers. comm., 1987).

Based on information obtained from exposures examined and roto-sonic drillholes, the complete stratigraphy is:

6) Organic material
5) Grey/brown silty-sand till
4) Lacustrine sediments (sand, silts, clays)
3) Fluvial sediments (sands, gravels)
2) Grey/brown sandy till
1) Bedrock

Some or all of these units are locally absent above bedrock.

Bedrock

Bedrock exposure is abundant but commonly masked by moss and lichen except in the northeast due to mine smelter emissions. The predominant rock types are metavolcanics and metasediments of the Amisk and Missi Groups and syntectonic felsic to intermediate intrusives (Pearson et al., 1986). Limited overburden drilling suggests a highly variable bedrock surface topography.

Glacial Till

Two tills previously detected in exposures and augerholes in the region (Schreiner,1984) were confirmed during the present investigation. These tills vary considerably in texture, composition, colour and appearance throughout the area, reflecting differing source material, mode of deposition and postdepositional processes.

The lower till is commonly grey to brownish grey, dense, and has a silty-sand matrix containing abundant granules. Subangular to angular clasts comprise 40 to 70 percent of the (gravelly) deposit. The texture of the lower till in this region differs from that in the La Ronge Belt. The clay content is similar, but the sand/silt ratio is higher, making it a sandier till. Preliminary results indicate that this till reflects the local bedrock composition. The grey variety is mainly derived from mafic intrusives and/or mafic to intermediate volcanics. Till originating from felsic to intermediate intrusives tends to be brownish and more sandy.

The upper till is thin and discontinuous, and more prevalent than in the Waddy Lake area (Campbell, 1986). Observations at 24 sites indicate a thickness of generally less than 2 m. This till is typically brown, due to oxidation, with a silty-sand matrix containing a lower percentage of smaller and more rounded clasts. Texture is very similar to the lower till, with only a slightly higher silt content. The composition indicates the incorporation of stratified sediments which have been overridden, possibly during a minor readvance of ice into the Lake Agassiz basin (Schreiner,1984).

Glaciofluvial Deposits

Less than 5 percent of the study area is covered by glaciofluvial sand and some gravel. These predominantly occur in association with deltaic sediments, and are interpreted as having been deposited in an ice contact/lacustrine environment at the ice sheet front during deglaciation. Small kame-like gravelly deposits and channel fills are also associated with these ice frontal environments.

Such ice contact/lacustrine deposits are restricted primarily to two areas. A long intermittent lineal deposit, generally less than 1 km wide, runs from Mosher Lake southwestward past Konuto Lake to Amisk Lake. The other deposit, which contains more coarse glaciofluvial material, forms a much broader belt extending southeasterly from north of Douglas Lake to Boot Lake. Till has been noted on the topographic highs in this deposit.

A small sand deposit just east of Birch Lake appears to be transitional between a fluvial and lacustrine environment.

Glaciolacustrine Deposits

The glaciolacustrine deposits comprise mainly clayey-silt to silty-clay, although fine sand is also found. These sediments are commonly laminated, and very discontinuous in extent and thickness. Silts and clays are commonly restricted to slopes and low-lying areas, and predominate around Amisk Lake and in the south.

Glaciolacustrine sediments were found at a maximum elevation of 335 to 338 m in eight locations, but are commonly below 320 m. As the maximum lake level is estimated to have been 400 to 427 m, complete submergence of the study area is probable (Schreiner,1984). The few poorly developed strandlines noted represent falling water levels as glacial Lake Agassiz drained from the area.

Organic Deposits

Most of the small lakes, and major creeks and rivers are bordered by wetlands. Muskeg occurs sporadically throughout the area. The southeast is dominated by large organic deposits interspersed with outcrop ridges. The drier muskegs tested are relatively shallow (less than 1 m) and overlie silts and clays. Drilling of several larger organic deposits indicates they are commonly underlain by glaciolacustrine sediments which often lie directly on bedrock.

Ice Direction Indicators

Throughout the study area, numerous striae and grooves were noted on outcrops. Roche moutonées are also prevalent. Crossing sets of striae were recorded at four locations. An older set indicates an ice movement direction of 190° to 208°. A younger set crosscuts at 216°, suggesting a readvance in a slightly more southwesterly

direction. Readings taken from numerous single sets throughout the study area reveal ice directions ranging between 190° and 214°, with the most common direction being 204° to 208°. This variation in direction is probably due to local bedrock topography.

Sample Analysis

Till sample analyses included geochemical analyses, heavy mineral separation and gold grain documentation. Fractionation tests were performed on selected samples containing gold in order to identify possible grain-size relationships. Selected samples were also subjected to textural analysis.

In all, 112 till samples (including bulk till samples) were analyzed at the SRC for lead, nickel, cobalt, copper, zinc, silver, arsenic, gold and tungsten. These samples were wet-sieved to 0.1 mm (-150 mesh) and analyzed by atomic absorption (GFAA).

The SRC employs a shaking table and Mosley superpanner for heavy mineral separation of the bulk till samples. The samples are panned manually to separate the gold grains, which are then described and counted before the concentrates are assayed. The results from the gold grain counts and the geochemical and heavy mineral analyses will be compared to determine the most representative analytical method.

These analyses of the tills will provide background information for interpretation of mineral distribution, especially gold, and should help to identify the till units most suitable for exploration sampling.

Summary and Conclusions

Although not all analytical results are yet available, several important preliminary observations are made:

1) Drift cover in the East Amisk Lake area is thin in comparison to the La Ronge Domain. The rugged bedrock topography in the north causes rapid lateral variation in drift thickness.

2) Two distinct tills are present: a) a thin and discontinuous upper grey/brown silty-sand till and b) a more prevalent lower grey sandy till. Lithlogical variations of the lower till reflect variations in local bedrock source, making it the preferred sampling medium.

3) Two ice frontal positions have been identified, marked by ice contact/lacustrine deposits, in the Mosher - Konuto - Amisk Lakes and Douglas - Boot Lakes areas. The Quaternary geology is complex in these areas.

4) Glaciolacustrine sediments are found at elevations as high as approximately 338 m. The entire area was inundated by glacial Lake Agassiz with a highest lake level estimated at between 400 and 427 m (Schreiner,1984).

5) Four sets of crosscutting striae indicate an older ice direction of 190° to 208°, which is overridden by a younger readvance in a more southwesterly direction at about 216°. The most common direction of ice flow is 204° to 208°.

6) Preliminary geochemical results suggest bulk till sampling is more effective than soil sampling for regional geochemical surveys in this region.

7) Preliminary results also indicate that the regional geochemical threshold values for gold are less than 17 ppb for the less than 0.1 mm till fraction and less than 5 gold grains in bulk till samples. These figures are low in comparison to Waddy Lake.

8) Drift prospecting has limited application in the East Amisk Lake area. The most useful technique is overburden drilling in topographical lows which are commonly muskeg filled.

Acknowledgments

The cooperation of the mining companies in allowing access to their properties is gratefully acknowledged. Special thanks to John Pearson, Resident Geologist, for his assistance and support during this summer's fieldwork.

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Integrative Interpretation of Exploration Surveys by Use of Image Analysis Techniques: Progress Report

by Michel Mellinger[1]

Mellinger, M. (1987): Integrative interpretation of exploration surveys by use of image analysis: a progress report; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

The general concepts underlying the use of image analysis techniques in the integrative interpretation of exploration surveys were presented earlier (Mellinger, 1986). An example of application to geochemistry can be found in Leymarie and Durandau (1985). Each survey is formatted into a raster image comprising a number of lines and rows of pixels ('picture elements'). Computer systems for remote sensing and image analysis can then be used to manipulate these surveys one at a time or in combination, permitting rapid, flexible and systematic interpretation of all survey data for the project area.

Acronyms Used in this Text

CEA-DAMN: Commissariat à l' Energie Atomique, Départment d' Approvisionnement en Matières Nucléaires;
CNRS: Centre National de la Recherche Scientifique;
INRIA: Institut National de Recherche en Informatique et Automatique;
MSS: Multi-Spectral Scanner;
SRC: Saskatchewan Research Council;
VLF: Very Low Frequency.

Project Specifications

A 21x21 km area covering the Carswell Structure (Athabasca Basin) was selected as a test area, and a common pixel size of 50x50 m was was selected for all surveys. Images were obtained by: 1) gridding of survey computer data file (geological surveys, topographic survey); 2) digitization of paper document (geological information); and 3) direct order (LANDSAT satellite imagery).

The geological map was used as a base map for the registration of all images.

A total of 17 images (data channels) were initially available for this study: These included airborne radiometrics (U,Th), Dighem resistivity survey, aeromagnetic survey (total field, vertical gradient), VLF survey (2 frequencies), gravimetric survey (Bouguer anomaly, residual anomaly, vertical gradient), topographic survey, compilation geology (lithology, structural and punctual information), and LANDSAT MSS imagery (4 channels).

Data Processing

Two computer systems with complementary capabilities were used for image manipulation and interpretation: 1) a typical remote sensing system: the DIPIX Aries II hardware/software system at the SRC Remote Sensing Centre; and 2) a generic image analysis system: the INRIMAGE software at the INRIA laboratories in Nice (France).

The remote sensing system proved most useful for tasks involving image registration and geometric correction, and some multichannel operations such as display and pixel classification.

The image analysis system proved most useful for tasks involving pixel value scaling in various formats, image thresholding, image masking, multichannel logical operations, and mathematical morphology (various object transformations).

Results

Results were reported in Leymarie et al. (1987) and are also presented here during the poster session. The main results of the project are as follows:

1) It has become possible to carry out a systematic interpretation of the survey data over the whole project area, whereas previously such interpretation was limited in extent due to time and cost constraints.

2) It has become practical to test at will various interpretative hypotheses involving data from one or more of the rasterized surveys, and to carry this out over the whole project area.

3) Decisions for long-term management of the property could be made with the assurance that no important data had been overlooked in the project area.

The following examples have been selected to illustrate the qualitative and quantitative benefits of using image analysis techniques for the integrative interpretation of areal surveys.

[1]Data Analysis Group, Resources Division, Saskatchewan Research Council, Saskatoon.

Example 1: Interpretation of U Radiometrics

Fig. 1 presents the steps followed to create a summary map of U anomalies for the project area; note that only one data channel (image) is used as initial input in this case.

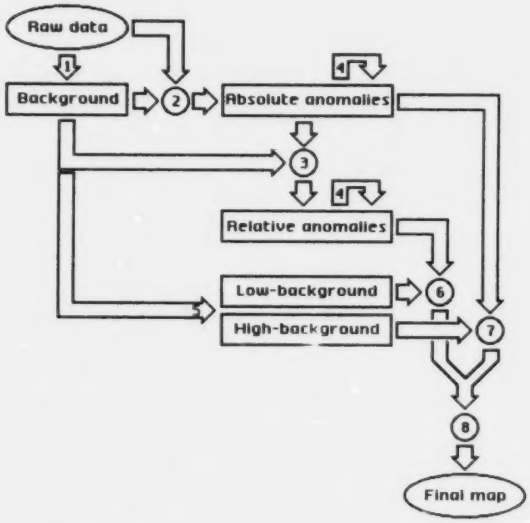

Figure 1 - Steps used to create a summary map of uranium anomalies for the project area (see text for an explanation of each numbered step).

The result combines, in one map only, relative anomalies in low-background areas and absolute anomalies in high-background areas, and thus presents a comprehensive evaluation of the project area with respect to U anomalies.

The steps used were as follows:

1) Calculation of the U background map - This was done by filtering the data with a statistical filter (window) which attributed to the pixel, located at the centre of the moving window, a statistical measure (20th persentile) of the distribution of U values within the window.

2) Calculation of the map of absolute U anomalies - This was done by substracting the background map from the raw data map and by keeping only positive pixel values.

3) Calculation of the map of relative U anomalies - This was done by dividing the map of absolute U anomalies by the background map.

4) Thresholding of both anomaly maps - This was done to reduce the number of calculated anomalies to a manageable size (50 to 100 in each case); the anomalies that were kept are those which were highest in value.

5) Partitioning of the background map into high-background and low-background areas.

6) Creation of the map of relative U anomalies in low-background areas - By definition, relative anomalies are used to detect subtle changes in low-background areas.

7) Creation of the map of absolute U anomalies in high-background areas - In such areas, absolute anomalies provide sufficient information.

8) Creation of the summary map of U anomalies: By merging the maps created in steps 6 and 7 above.

Example 2: Flexibility in Geophysical Interpretation

For the airborne magnetic survey, both the total field and vertical gradient data were obtained from the geophysical contractor. This produced good results for the total field image; however, the image of the vertical gradient was poorly contrasted, probably due to the use of a filter size that was too large.

The vertical gradient was then recalculated on the image analysis system from the total field image. The resulting magnetic vertical gradient displayed much better scale dynamics (contrast) than that obtained directly from the contractor. This shows that when users have control over some processing of their geophysical data, results better suited to a specific project may be obtained. It can thus be foreseen that, before very long, users will request geophysical survey results to be provided to them as image files that can be further manipulated by them in the office using the appropriate software on a desk-top computer.

(Similarly, a vertical gradient map was calculated for the resistivity survey and recalculated for the gravity survey).

Conclusions

Integrative interpretation of exploration surveys by use of image analysis techniques is both effective - by producing information of interest where it was impractical before - and efficient - by providing rapid and flexible data processing and interpretation.

It became apparent, during the course of this project, that flexibility in image interpretation cannot be provided by one type of system only. Both systems used here - a typical remote sensing system and a generic image analysis system - have strengths and weaknesses, as discussed above. ('Data Processing' paragraph).

Acknowledgements

This progress report is based on the Amok Image analysis (Analyse d'Image Amok) project, carried out by Pierre Leymarie (CNRS-INRIA, Nice, France) and the author. The work was carried out using the SRC remote sensing system and the INRIA image analysis system. Funding for the project was provided by AMOK Ltd./Ltée (Saskatoon), the CEA-DAMN (Paris, France) and the SRC (Saskatoon). The efforts of Roger Lainé (AMOK Ltd./Ltée) and Jacques Dardel (CEA-DAMN) in making this project possible have been particularly appreciated.

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Lithogeochemistry and Metallogenesis of the Rio Gold Mine, and Comparative Geochemistry from the Flin Flon and Amisk Lake Areas

by Michel Mellinger[1] and J.G. Pearson[2]

Mellinger, M. and Pearson, J.G. (1987) Lithogeochemistry and metallogenesis of the Rio gold mine, and comparative geochemistry from the Flin Flon and Amisk Lake areas; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

Geochemical data may be interpreted with the help of multivariate descriptive statistical techniques, which display data patterns in a form that permits rapid and synthetic interpretation. Work carried out over the past few years at the Saskatchewan Research Council (SRC) by the Data Analysis Group has demonstrated that simple interpretation strategies produce very useful results not only for the geologist and metallogeneticist, but also for the explorationist. A series of tutorial papers on that topic have been published recently by M.M: the first article explains the general concepts and methods of multivariate data analysis (Mellinger, 1987a), the second presents and illustrates the use of the most powerful of these methods for geolocial and geochemical applications (Mellinger, 1987b) and the third presents a summary of the research work done at the SRC during the past few years and its applications to field data (Mellinger, 1987c).

The two latest geochemical interpretation projects completed at the SRC deal with data collected as part of work carried out by Saskatchewan Energy and Mines (SEM) and the SRC, specifically 1) surface and underground data collected at the Rio mine by both authors, and 2) regional surface data collected by J.G.P. as part of an evaluation of gold metallogeny in the Flin Flon and Amisk Lake areas. This paper presents some of the highlights of each project. Full results of each study will be published elsewhere.

A) Metallogenesis of the Rio Gold Mine

Samples from the Rio mine property were collected on surface during geological mapping (Pearson, 1984) and in underground workings for specific geochemical study of the mineralization (Pearson, 1984; Mellinger, 1986). The samples were analyzed for a broad suite of major and trace elements and all geochemical data merged into one data file. The geochemical data patterns were interpreted using correspondence analysis, a descriptive factor analysis method (see references cited above). Major and trace elements were treated separately and data patterns from each set of elements were then correlated with each other. Preliminary results were presented at the GAC/MAC 1987 Annual Meeting (Pearson and Mellinger, 1987).

In addition to providing information about sample petrography and petrological classification (not shown here), major element patterns display interesting information about host rock alteration and mineralization at the Rio mine, particularly when projected on the plane formed by the third and fifth factors (Fig. 1). Two data trends are apparent on this plot, which diverge in the following manner:

1) One trend extends towards K_2O, in samples affected by potassic alteration. All except three samples contain no gold mineralization, but Cu correlates well with this potassic trend. The three samples not showing gold mineralization contain gold in quartz-carbonate veinlets.

2) The other trend extends towards iron due to the presence of pyrite. Au, Pb, W and Ag correlate well with this pyritization trend. All samples except one which project along this trend contain gold mineralization.

   The relationship of As to either trend is not clear, because As projects between the two trends.

It is thus very clear that gold mineralization was introduced at the Rio mine at the same time as pyrite was precipitated in the host rocks, as suggested earlier for this and other Saskatchewan epigenetic gold deposits (Mellinger, 1986). Potassic alteration developed during a separate hydrothermal event which introduced some Cu mineralization, possibly as part of a porphyry system (Pearson et al., 1986).

The apparently divergent relationship between gold and copper mineralization at the Rio mine was further tested by analyzing data patterns for the ore elements Au, S, W, and Cu. Correspondence analysis was again the statistical method used, but a disjunctive coding of the data was selected to permit observation of nonlinear patterns (see Mellinger (1987b) for an explanation of this type of coding and its purpose). The concentration intervals used for this data recoding are indicated on Fig. 2 (upper left). The resulting patterns are again very clear on this Factor 1 - Factor 2 plot (Fig. 2).

[1]Data Analysis Group, Resources Division, Saskatchewan Research Council.
[2]formerly Saskatchewan Energy and Mines; currently Coombe Geoconsultants Ltd., Regina.

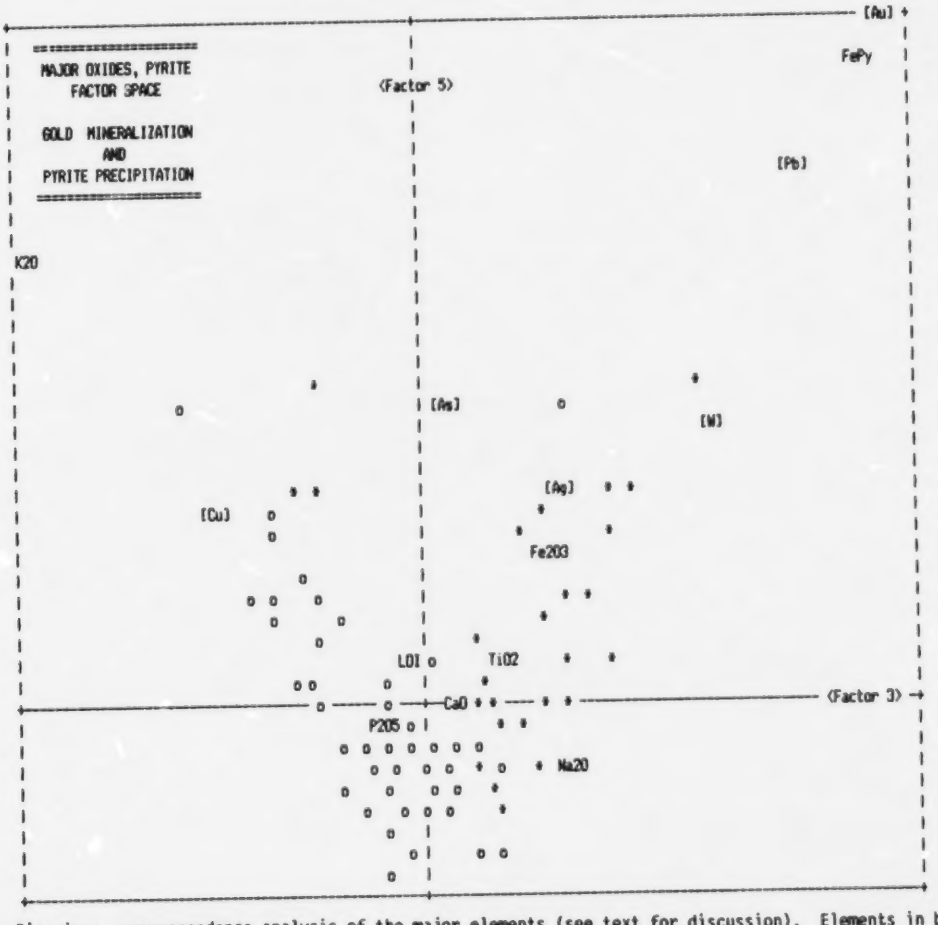


Figure 1 - Rio mine: correspondence analysis of the major elements (see text for discussion). Elements in brackets are simply projected onto this factorial plane and did not participate in the calculation of the factors; other elements/oxides were involved in the calculation of the factors and patterns displayed. Each symbol represents a rock sample, and also indicates whether a sample contains less than 100 ppb gold (open circles) or more than 100 ppb gold (stars).

1) Increasing gold concentration in the samples (Au1 to Au2 to...Au6) follow an arcuate pattern closely matched by increasing concentrations in sulphur (S1 to S2 to ... S5 and [S6]) and in tungsten (W1 to W2 to ...[W5]). Au, S and W are thus closely associated in mineralization.

2) Increasing copper concentrations (Cu1 to Cu2 to ... Cu4) follow a general path exactly opposite to that of the previous elements, demonstrating that Cu has not been introduced during the event responsible for the gold mineralization.

Regional Geochemcial Patterns of the Flin Flon and Amisk Lake Areas

Samples were collected over several years by J.G.P. during the systematic study of gold metallogeny in the Douglas Lake, Phantom Lake and Amisk Lake areas (Pearson, 1979 to 1984; Pearson and Galley, 1985). The samples were analyzed for a broad suite of major and trace elements and all geochemical data merged into one data file. Samples were also identified according to their regional provenance so that a comparison between the Douglas Lake, Phantom Lake, East Amisk Lake and West Amisk Lake areas could be carried out.

The geochemical data patterns were interpreted using correspondence analysis following the same strategy as in the first project above.

Major element patterns provide information about the following:

1) General petrochemistry of the samples (not shown here): At Amisk Lake, an approximately equal proportion of mafic and felsic rocks are

present; Phantom Lake rocks appear to be generally similar to those at Amisk Lake. The Douglas Lake rocks are mainly mafic and show a strong ferrous character, whereas the less prolific felsic rocks show a strong sodic character. In all areas sampled, intermediate rocks are rare.

2) Alteration of the samples (not shown here): A carbon dioxide alteration trend is present in all samples probably due to metamorphic alteration. A K_2O alteration trend is also present in the Amisk West and Phantom Lake samples.

Trace element patterns fall into three groups:

1) Lithophile patterns (not shown here): These involve Ba, Sr, V and Cr, which define a tetrahedron in the factor space with one element at each apex. Ba and Sr variations are related to felsic rocks and are differentiated only at Douglas Lake (Sr character related to the sodic character present there in felsic rocks) and Phantom Lake (Ba character, as yet unexplained). V and Cr variations are related to mafic rocks and are differentiated at Amisk Lake (strong Cr character as a whole with some V character also at Amisk West) and Douglas -

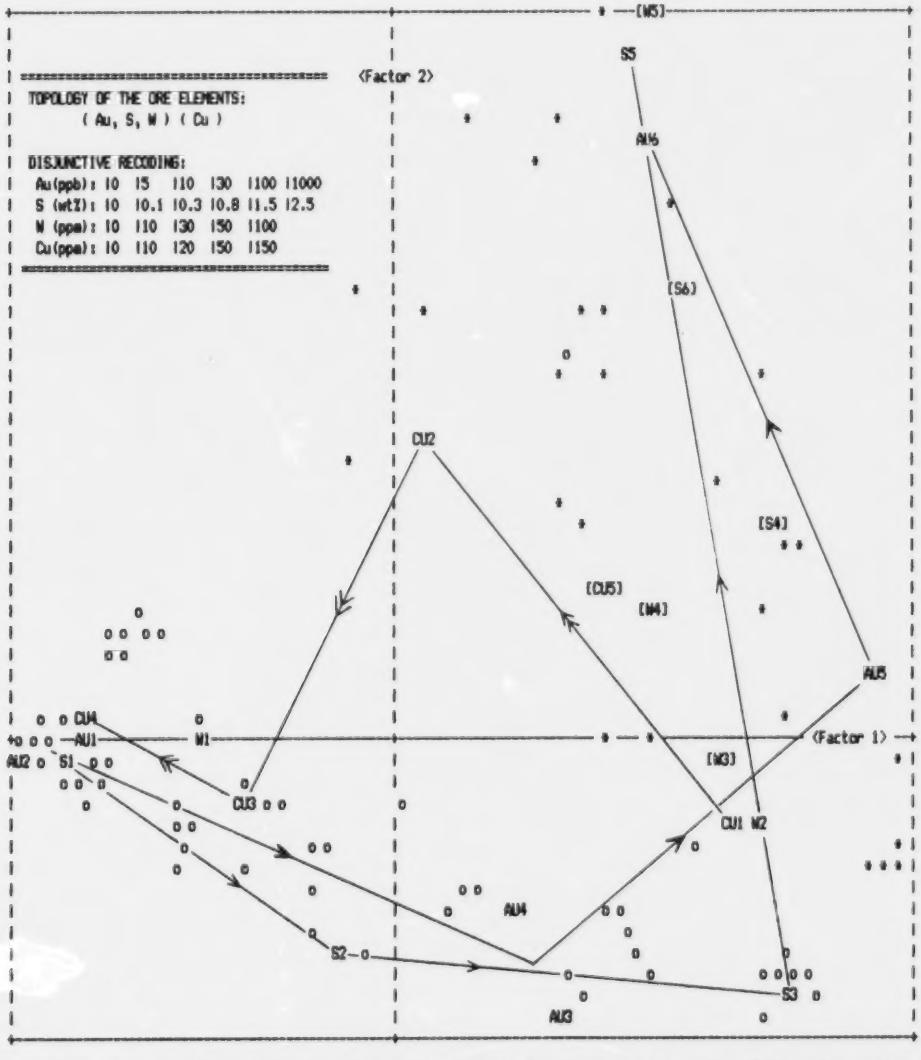
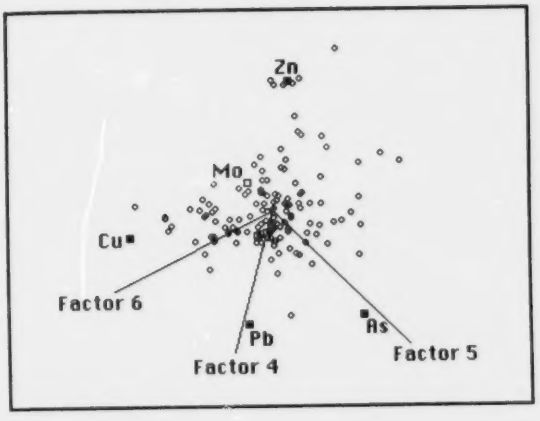
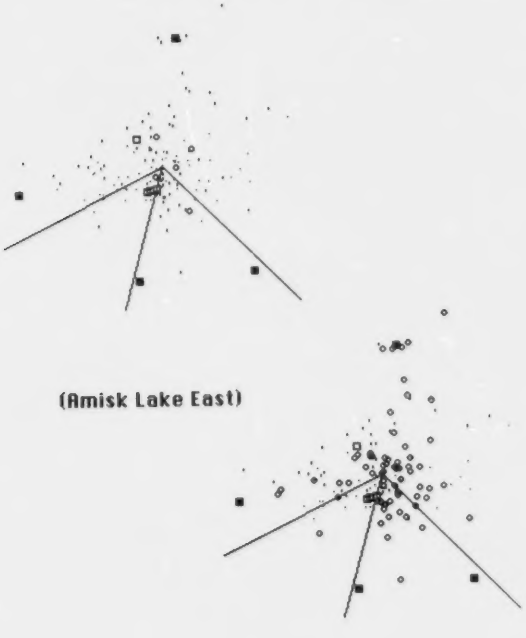


Figure 2 - Rio mine: correspondence analysis of the ore elements Au, S, W and Cu, using disjunctive coding (see text for discussion). Concentration ranges used for disjunctive coding are listed in the upper left. Lines were drawn to follow increasing concentrations of Au, S and Cu (a similar line can be drawn for W but was omitted here to avoid cluttering). Each symbol represents a rock sample, and also indicates whether a sample contains less than 100 ppb gold (open circles) or more than 100 ppb gold (stars). This can be confirmed directly by noting that intervals Au5 and Au6 define all gold concentrations greater than 100 ppb.





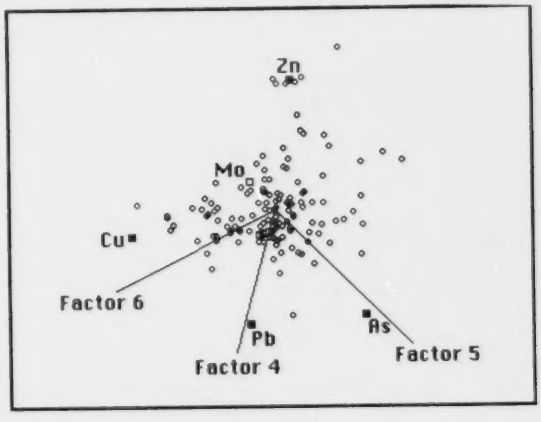
(Amisk Lake East)

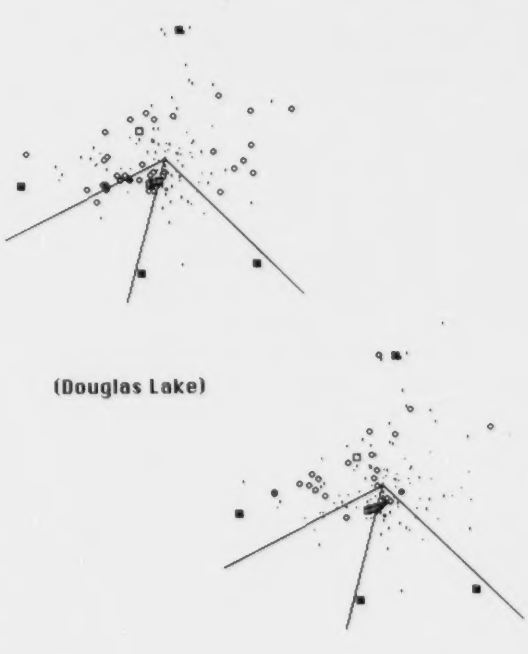
(Amisk Lake West)

Figure 3 - Flin Flon - Amisk Lake area: correspondence analysis of the trace elements, chalcophile patterns with details for the two Amisk Lake subareas (see text for discussions). This is a projection of the three-dimensional patterns displayed by factors 4 to 6, oriented in such a way that all chalcophile information is displayed properly; this projection is interpreted in the same way as a multipole petrological diagram. The framed projection (top) is for reference, with all samples represented by open circles and elements and factors named; the plots at the bottom are the same as the top plot but with samples from each specific subarea (as noted) displayed as open circles, while samples from other subareas are shown as dots.

Phantom Lakes. The last-mentioned area has a strong V character as a whole, which is more pronounced at Douglas Lake, probably due to a more distinct TiO_2 character (related to the strong ferrous character) of the mafic rocks.

2) Chalcophile patterns (Figs. 3 and 4): Cu, Pb, Zn, As and, to a small extent, Mo are the end





(Douglas Lake)

(Phantom Lake)

Figures 4 - Flin Flon - Amisk Lake area: correspondence analysis of the trace elements, chalcophile patterns with details for the Douglas Lake and Phantom Lake subareas (see text for discussion). Plot orientation and notations are the same as for Fig. 3.

members of these patterns which can be displayed in one factor plot combining factors 4 to 6; rocks from Amisk West have a distinct Zn-As-Pb character with some Cu signature (Fig. 3, bottom right); conversely, rocks from the Douglas - Phantom Lakes area as a whole show a clear Cu character with some Zn component (Fig. 4, bottom left and right). This shows that the metallotects of these two areas are clearly different;

3) Gold mineralization (not shown here): The only notable (although weak) correlation between gold and other elements was detected in major element patterns, where gold shows an association with potassic alteration, projecting in the same direction as K_2O in the major element factor space; no correlation between gold and other trace elements was present in the trace element factor space; however, it should also be noted that sulphur was not analyzed (neither was tungsten) in the samples under study and that, as a consequence of the absence of this critical variable for gold mineralization, gold patterns cannot be characterized properly.

In addition to interpreting geochemical patterns for major and trace elements, the study examines anomaly threshold values for chalcophile elements in the sampled region as a whole using concentration distributions and probability cumulative plots. Rather than defining one threshold value for each element, the techniques used made it obvious that several anomalous subpopulations often exist for a single element; therefore, several anomalous concentration ranges were defined where required. These anomalous concentration ranges can be used most effectively in lithogeochemical exploration programs by plotting each sample on survey maps or drillhole cross-sections with a different symbol for each concentration range defined here. The background and anomalous concentration ranges are listed in Table 1.

Conclusions

In addition to further demonstrating the power of correspondence analysis as an interpretation tool in geochemistry, several important conclusions can be drawn for the two projects highlighted here.

Rio Mine

1) Gold mineralization at the Rio mine is drectly associated with pyrite precipitation and also involves a clear, although weaker, lead, tungsten and silver mineralization.

2) Gold mineralization at the Rio mine is not associated with potassic alteration; some weak copper mineralization is associated with this alteration and was thus introduced separately from gold mineralization.

Table 1 - Background and Anomalous Concentration Ranges for Chalcophile Elements in the Flin Flon - Amisk Lake Region (see text for explanation)

	Background	Anomaly 1	Anomaly 2	Anomaly 3	Anomaly 4
Au (ppb)	0-6	7-17	18-(22)	>(37)	-
As (ppm)	0.0-0.9	1.0-2.9	3.0-5.7	5.8-11.9	>12.0
Cu (ppm)	0-100	100-300	>300	-	-
Mo (ppm)	0-5	>6	-	-	-
Pb (ppm)	0-20	21-33	34-45	>46	-
Zn (ppm)	0-155	156-299	>300	-	-

Notes:

Au - Not enough data available between 22 and 37 ppb.

As - The first two anomaly ranges apply in particular to the Douglas Lake and Phantom Lake areas.

Cu - Use these thresholds with care because Cu has a strong lithophile component which masks its chalcophile component; a detailed study of these two components (not presented here) shows that this masking effect is very important in the 'background' range and becomes less critical for higher ranges. Only multivariate analysis will separate both components for a given set of samples, as was done in this study.

Mo - Due to poor analytical detection limits (usually at about 5 ppm for routine analytical techniques) more detailed ranges cannot be defined.

Pb - No particular difficulty was encountered.

Zn - The same remarks apply as for Cu. However, the two anomalous ranges defined here are fairly clear in our data, while the background range may be pessimistic.

Regional Lithogeochemistry

1) The Amisk Lake and Douglas - Phantom Lakes areas display some differences in volcanic lithologies, with felsic-mafic members distributed in a clear bimodal manner; lithophile trace elements (Ba, Sr, V, Cr) confirm and shed further light on these differences.

2) If a metamorphic CO_2 alteration is present in all study areas, a potassic alteration trend is detected only in rocks from the Amisk West and Phantom Lake areas.

3) Chalcophile trace element associations are clearly different for the Amisk Lake area as a whole (Zn, Pb, As, some Cu) and the Douglas - Phantom Lakes area as a whole (Cu, some Zn); gold mineralization is present in all study areas.

4) Anomalous concentration ranges have been defined for all chalcophile elements (Au, As, Cu, Mo, Pb, Zn) for the study area, and should prove useful in lithogeochemical exploration.

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Current Research in Mineral Deposits at the Saskatchewan Research Council

by David Quirt[1] and Matt Rees[2]

Quirt, D. and Rees, M. (1987): Current research in mineral deposits at the Saskatchewan Research Council; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

During the past two years, mineral deposit research at the Saskatchewan Research Council (SRC) has moved away from uranium-related studies toward those related to gold and platinum group metals, in response to growing industry activity in exploration for these commodities. A number of uranium-related projects, including those concerning the Athabasca Group, are in the final stages of preparation, and specific summaries and reports are expected to be available early in 1988. Two gold studies were ongoing in 1987: one in the Goldfields area as part of the SRC's Beaverlodge Project and a new study initiated this summer in the Waddy Lake - Tower Lake area.

Waddy - Tower Lakes Gold Studies

The Waddy - Tower Lakes program will geochemically characterize selected intrusive bodies in the broad Waddy Lake area, with the objective of determining any relationship between gold mineralization, and the intrusives. A number of intrusives were identified for examination on the basis of previous work (e.g., Harper et al., 1986; Johnston, 1981; Watters, 1985, 1986). Samples collected and geological information provided by C.T. Harper of Saskatchewan Energy and Mines on the Kenwood Lake, Nistoassini Lake, Boundary Lake, Contact Lake, Payn Creek and West Lower Waddy Lake Plutons, and the Dog Creek and Tower Lake Stocks will be integrated into this study. In addition, a start was made this summer on resampling and remapping portions of the Nistoassini Lake and the Kenwood Lake Plutons. A total of 226 samples were collected from the Nistoassini Lake and Kenwood Lake Plutons, while an additional 164 samples were obtained from the other units.

Preliminary observations on the Kenwood Lake and Nistoassini Lake Plutons are as follows:

1) the Kenwood Lake Pluton, sampled by three traverses, appears to be quite monotonous in composition and unzoned. At both the north and south contacts, the pluton is surrounded by a halo of altered 'granitized' material. Along the south contact, west of Looney Lake, large fault displacement has brought relatively unmetamorphosed sediments into contact with the granitized material along the contact. Sampling was hampered by weathered outcrop.

2) five traverses made across the Nistoassini Lake pluton crossed the southern, western and northeastern contacts and the metapyroxenite units within the pluton. The pluton shows a somewhat different character to that of the Kenwood Lake Pluton. Distinct but subtle compositional zoning is recognizable in the field and will likely be more evident from petrographic examination. This pluton also shows the effects of hematization and deformation accompanying retrograde metamorphism, in contrast to the Kenwood Lake Pluton which shows little evidence of these features. Deformation appears to increase northwesterly toward the Central Metavolcanic Belt, obscuring the distinction between the Nistoassini Lake Pluton and the Macoun Lake pluton in the north. The traverses across the metapyroxenite bodies gave preliminary indications of substantial differences in sulphide content.

Sample preparation for petrography and geochemistry is presently underway. All samples will be analyzed for Al, Fe(total), K, Mg, Ca, Na, Ti, P, Mn, CO_2, FeO, LOI, Ni, Cu, Pb, Zn, Li, Rb, Sr, Au, Ag, As, V, U, Th, Co, Mo, Zr, Cd, Cr, Be, B, Y, La and Ba. Selected samples will also be analyzed for Si, Nb, Hf, Ta and rare earth elements. The petrographic examination of the samples will be augmented by X-ray diffraction mineralogical analyses.

Goldfields - Beaverlodge Area

Gold metallogenetic research by the SRC in the Goldfields region has concentrated on areas around the former Box and Athona mines and the Frontier prospect. Sampling was completed this summer, and a start was made on sampling of the former Nicholson mine area. A description of the general geology of the Goldfields area can be found in Sibbald (1984).

Analytical results from the Frontier prospect have been used in mass balance calculations to evaluate the nature of metasomatic replacement in the Frontier granite. This granite is massive, veined with quartz and apparently enclosed by sericitic feldspathic quartzite, which displays sedimentary features such as cross-bedding and pebbly layers. It differs from the metasomatic Box and Athona

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Table 1 - Typical Geochemical Analyses, Frontier Area

	Quartzite	Transitional	Granite
n	18	10	8
SiO_2[1]	74.97	75.27	83.15
Al_2O_3	12.36	12.39	8.38
Fe_2O_3[2]	1.67	2.04	0.85
FeO	0.65	1.04	0.54
CaO	0.10	0.12	0.08
K_2O	7.52	7.09	6.35
MgO	1.27	0.98	0.24
Na_2O	0.37	0.40	0.31
H_2O	1.16	1.03	0.24
Trace elements			
S	37	28	486
Ba	1124	1186	986
Au	40	15	256
Pt	<10	<10	<10
Pd	<2	<2	<2

All oxides in weight percent; S and Ba in ppm; Au, Pt and Pd in ppb.
[1] SiO_2 by difference
[2] total iron as Fe_2O_3

granites, primarily by its finer grain size and by an absence of albite. The transition from quartzite to granite is gradational over several metres across strike and an even greater distance along strike. It is marked by the appearance of patches and bands of relatively massive pink pyritic quartz-potassium feldspar rock, accompanied by a loss of sedimentary features. Quartz veining is rare in the host quartzite, but is ubiquitous in the core of the granite.

Samples have been grouped into 1) quartzite, 2) transitional rocks and 3) granite. Initial results indicate little difference in the chemistry of the quartzite and transitional samples (Table 1.) There is, however, a significant difference between the quartzite and transitional rocks and the granite itself, which shows a moderate to strong depletion in major elements. Mass balance calculations indicate a small net loss of Al_2O_3 and K_2O in the granite, and greater losses of the other major elements (Mg, Ti, Fe) assuming either zero volume change or a small volume decrease. An exception to this trend is SiO_2 which is somewhat higher in the granite.

Trace elements occurring in moderate to moderately high concentrations (e.g., B, Ba) have been removed to a greater or lesser degree during the granite forming process. The only trace elements to show a net increase are Au, S and, to some extent, As. Au and S exhibit some correlation, but high gold values do not necessarily have high sulphur values associated.

These data suggest that the alteration of quartzite to granite was due not to potassium metasomatism but to redistribution and recrystallization, with the disappearance of sericite and the appearance of additional potassium feldspar. Sufficient potassium is present in the host quartzite to account for that in the granite (Table 1). The destabilization of the hydrous minerals due to a low water activity of the alteration fluid was accompanied by a depletion of many major and trace elements. It is not certain whether the gold/sulphur enrichment occurred at this time. Final interpretation awaits the analysis of more samples.

Study of the gold mineralization at the Box, Athona and Frontier properties is also being undertaken under SRC sponsorship by Matt Rees at the University of Saskatchewan. Included in this work are fluid inclusion investigations of quartz in gold- and uranium-bearing veins, as well as in the host granite, and stable isotope analyses of selected minerals from the same material.

Fluid Inclusion Studies

The fluid inclusion work reaveals the presence of similar sets of inclusions in the gold-bearing quartz veins at the Box, Athona and Frontier properties, suggesting that the three deposits are related. There also appears to be no detectable difference in the populations of inclusions between gold-bearing and barren veins in these deposits.

The most likely primary inclusions (representative of fluids from which the quartz veins crystallized) are three-phase CO_2-H_2O fluids which have a final homogenization temperature of 275 to 325°C. The melting temperature of carbon dioxide ice in the inclusions varies slightly from -56.6 to -56.8°C, suggesting the presence in small quantity of either CH_4 or N_2. The amount of CO_2 present varies in samples from the different deposits, but overall is 25 to 50 weight percent of the inclusion. Freezing point depression of water ice indicates the water has a low salinity, less than 5 weight percent NaCl equivalent.

Three generations of secondary fluid inclusions have been recognized. They occur along healed fracture planes in the quartz, and are representative of fluid events that took place after the emplacement of the quartz veins. One generation is marked by low density vapour-rich inclusions which homogenize below room temperature at 10 to 14°C. If the vapour were pure CO_2, this would indicate an anomalously low pressure (50 to 70 bars) for their formation. Consequently, the vapour is

probably a mixture of species such as CO_2, CH_4 and N_2.

Two-phase H_2O inclusions of the other two generations homogenize at 200 to 275°C and 120 to 185°C, respectively. The large temperature ranges are a result of the combination of data from the three deposits; however, within deposits the temperature ranges are narrower. Both generations also have low salinities, being less than 5 weight percent NaCl equivalent.

The events represented by the secondary inclusions are not yet positively identified. Current fluid inclusion studies of other types of mineralization (U, Au, PGM) in the area are providing several possibilities. The lower temperature, two-phase H_2O iclusions may be related to those in the uranium-bearing veins described below.

Uranium-bearing veins, dominantly composed of euhedral quartz and dated by Koeppel (1968) at approximately 1100 Ma, crosscut gold-bearing quartz veins in the Box and Athona granites. Primary fluid inclusions from the quartz in these veins are two-phase H_2O, with salinities of less than 5 weight percent NaCl equivalent. Homogenization temperatures range from 140 to 180°C. The inclusions also contain low to moderately birefringent minerals which are insoluble upon heating, and which occur as individual light green plates, or as radiating plate bundles. The latter, although not yet positively identified, are suspected to be an illite group mineral.

Stable Isotope Studies

Preliminary stable isotope analyses have been carried out on both the gold-bearing veins and the host granites. Data collection had been hampered by poor exposure, but recent trenching by the Kasner Group on the Box and Athona properties permitted the collection of virtually complete vein mineral suites this summer.

The $\delta^{18}O$ values of vein quartz from the Box, Athona, and Frontier properties all fall in the range +10.8 to +11.6 per mil. These values are slightly less than $\delta^{18}O$ values of vein quartz from the Abitibi area (compiled by Kerrich, 1987), but similar to published values from Star Lake and the Flin Flon - Amisk area (Kyser et al., 1986). A temperature of approximately 450°C has been calculated for the formation of the veins based on the values of coexisting vein quartz and chlorite at the Frontier property. The difference between this temperature and the 300°C fluid inclusion homogenization temperature suggests that a pressure correction of approximately 1 kb is required for the fluid inclusion data, and that minimum pressures during vein formation were about 1.5 to 2 kb.

The $\delta^{18}O$ values of vein quartz combined with the calculated temperature of formation in turn allow calculation of the stable isotope compositon of the mineralizing fluids. On this basis, the $\delta^{18}O$ value of the fluid suggests a metamorphic origin, as do the preliminary δD values of the vein chlorites (-75 to -80 per mil). The $\delta^{18}O$ values of coexisting quartz and feldspar from the Athona granite suggest that the mineral pair may have retained an original magmatic or magmatically related equilibrium. This conclusion is based on only two mineral pairs, and is therefore highly tentative.

Two preliminary $\delta^{34}S$ values of vein pyrite from the Box and Frontier properties fall in the range +1.2 to +1.4 per mil. The Frontier pyrite sample contains visible gold in narrow deep channel-like striations on crystal faces of the pyrite. These sulphur isotope values are similar to those reported from Star Lake and the Flin Flon - Amisk area by Kyser et al. (1986). Recent collection of vein mineral suites, which include quartz, chlorite, feldspar, tourmaline, pyrite, chalcopyrite, sphalerite, galena and bornite for stable isotope analysis will provide further data for the determination of the fluid history and mineralization of the Goldfields district.

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SOUTHERN STUDIES

Metallic Mineral Occurrences in or under the Phanerozoic Rocks of Saskatchewan

by D.F. Paterson

Paterson, D.F. (1987): Metallic mineral occurrences in or under the Phanerozoic rocks of Saskatchewan; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

In Saskatchewan the Precambrian basement is exposed in the north and slopes to the south where it is covered by a progressively thicker sedimentary sequence of Phanerozoic age. This sediment reaches over 3000 m in the southeast, reflecting the Williston Basin structure that extends northward from North Dakota.

The mineral wealth of southern Saskatchewan includes oil, gas, coal, potash, sodium sulphate and bentonite. These are well known, but there are occurrences of metallic minerals which also warrant consideration. This paper summarizes those occurrences known in the sedimentary rocks or in the igneous/metamorphic basement below them. Though not economically important today, some of these have been exploited in the past and others have the potential for future development. Published references have been given where available. Otherwise the original documents on which this paper is based can be consulted in the Mineral Assessment Section, Saskatchewan Energy and Mines, Regina.

Gold

Placer gold has been reported from four areas in southern Saskatchewan (Coombe, 1984). The principal of these is the North Saskatchewan River between the Alberta border and Prince Albert (1a on Fig. 1). Gravels have been worked intermittently since 1859 by dredging and sluicing at many places along this stretch and, although the amount of gold recovered has been poorly documented, some 275 oz. are known to have been taken in the four years from 1938 to 1942. There are still some active claims along this part of the river. Why, also, should there not be gold to the east of Prince Albert?

Gold was also found in the Waterhen River area (1b) and some surrounding creeks in 1926 (Coombe, 1984). The area is about 185 km north of North Battleford. The gold recovered was reported to be exceedingly fine. There appears to have been little, if any, production.

On the east side of the province, gold has been panned in small quantities from the sands and gravels around Leaf Lake (1c) in the Pasquia Hills, (Beck, 1967).

The other occurrence reported is on a tributary draining Fife Lake (1d) in the extreme south (Coombe, 1984). A large number of claims were staked there in 1931 but investigations by the then Department of Natural Resources failed to find any gold at all. So this showing should perhaps be classed as "not proven".

In summary, placer gold has been found at widely separated localities in the province and these areas might well be worth a second look. Other similar areas no doubt exist.

It would be interesting to know more about the gravels in buried river valleys, as shown on the Geological Map of Saskatchewan by Whitaker and Pearson (1972). Possibly the Battleford Valley, and the northwestern portion of the Hatfield Valley, have the same potential for gold production as the North Saskatchewan valley which area they previously drained.

Gold occurs on the Precambrian Shield in situations which suggest strong possibilities of it also being present under the contiguous Phanerozoic rocks. Around the Amisk Lake-Flin Flon area for example there are many showings, and in general the rocks strike north-south under the sedimentary cover. Showings at Brownell Lakes and Wapawekka Lake are along an east-west strike, which likewise carries the host rocks under the sedimentary cover. And the important finds in the La Ronge Belt - Waddy Lake, Star Lake, Sulphide Lake (Coombe, 1984) - are along a northeast-southwest trend, which disappears under the cover rocks south of La Ronge.

The possibility exists, therefore, not only for Precambrian occurrences under the Phanerozoic, but also for post-Precambrian placer deposits in ancient channels in the sedimentary cover.

Uranium

Anomalous concentrations of uranium have been detected at widespread localities in southern Saskatchewan. Of particular interest are the Uppermost Cretaceous and Tertiary rocks of the extreme southwest (2a), because of the lithological and stratigraphic similarities to the host rocks of uranium mines in Wyoming. Several explorations have been conducted in this area, including radiometric surveys, geochemical analysis of well waters, biogeochemical sampling, drilling and surface prospecting. Concentrations up to 400 times background were found. It appears that organic materials, in particular lignite and fossil bone, have locally concentrated the uranium,

presumably from metal-rich waters. Concentration gradients were found in some sandstones, possibly palaeochannel fills, but concentrations found were not high enough to be economic. It remains possible that somewhere in this southwest region, which covers about 5000 km^2, concentrations high enough to warrant mining might be present.

Substantially further north (2b), a track-etch survey showed several anomalies south of the Duddrige

1 Gold
- a – North Saskatchewan River
- b – Waterhen River
- c – Leaf Lake
- d – Fife Lake

2 Uranium
- a – Southwest Saskatchewan (several locations)
- b – South of Duddrige Lake
- c – Red Earth Indian Reserve

3 Manganese
- a – Northern edge of Pasquia Hills
- b – Little Emmeline Lake

4 Copper, Zinc, and Lead
- a – Hanson Lake
- b – Bigstone Lake
- c – Miskas Lake
- d – Peter Pond Lake
- e – South of La Ronge

5 Iron
- a – Choiceland anomaly
- b – Kelsey Lake anomaly
- c – Miami Hudson Bay No. 1 Nut Mountain well

6 Mercury
Fleury Pt., Peter Pond Lake

Figure 1 – Locations of metallic mineral occurrences referred to in the text.

Lake deposit. The anomalies appear to be along the edge of a palaeovalley cut into Precambrian rocks.

In the eastern part of the province, uranium anomalies associated with helium gas were explored in the region of the Red Earth Indian Reserve (2c). No high concentrations were found and no plausible mechanism for their occurrence was formulated. Possibly locally occurring shales of the Boyne and Favel Formations (Cretaceous) have led to concentrations of uranium. The shales are very rich in organic matter, to the extent of being informally called "Oil Shales", and show raised radioactive readings on geophysical logs.

Manganese

Beck (1974) reported that the basal 100 m or so of the Upper Cretaceous Riding Mountain Formation in the Pasquia Hills area of east-central Saskatchewan contains nodular concretions rich in iron and manganese. Analyses showed these nodules to contain an average 20 percent iron and 17 percent manganese along with minor or trace amounts of barium, chromium, cobalt, copper, gold, lead, molybdenum, nickel, silver, titanium, vanadium, zinc and zirconium.

The geology of the area suggests that the nodules are present over an area of some 400 km^2. However, the potentially mineable area consists of a 60 km strip around the northern tip of the Pasquia Hills (3a) where a stripping ratio of 0.5 (waste) to 1.0 (ore) or better exists. This gives a potential of 5 to 6 million tonnes of nodules.

Manganese-rich sands have been reported from Little Emmeline Lake (3b), 70 km west of La Ronge (Simpson, pers. comm.). They appear to be of recent origin but their thickness and lateral extent are unknown.

Copper, Zinc and Lead

Base metal deposits on the Precambrian Shield have been mined in Saskatchewan for many years. The Flin Flon Mine (chalcopyrite and sphalerite) and the Anglo-Rouyn Mine (chalcopyrite) are examples. Galena and sphalerite were mined at the Western Nuclear Mine, Hanson Lake (4a) and there is a showing of the same minerals at Segment Lake.

The Hanson Lake deposit was right on the edge of the shield and, in fact, the mine buildings were built on the adjacent Ordovician dolomites. It is probable that other deposits are present below the sedimentary cover and two bodies have been outlined at Bigstone Lake (4b) and Miskas Lake (4c). These bodies are both chalcopyrite and sphalerite in the Precambrian basement under about 50 m of sedimentary cover. The Bigstone Lake deposit is estimated at 3.5 million tonnes grading 3.5 percent copper and 600,000 tonnes grading 7 percent zinc. The scatter of showings all along the shield edge suggests that most of the shallowly-buried Precambrian is prospective.

Base metals have also been encountered hosted within sedimentary carbonate rocks. Chalcopyrite has been reported in fractures within Devonian rocks (Fuzesy, 1980) near Peter Pond Lake (4d) and south of La Ronge (4e). Also south of La Ronge, visible galena and anomalous zinc values have been reported from Devonian rocks. The Meadow Lake Escarpment is a subsurface structure that runs WSW-ENE through that area and could bear some relationship to the mineralization.

Iron

Substantial reserves of iron have been established in the Precambrian basement rocks in southern Saskatchewan, particularly in an area some 100 km east of Prince Albert near the town of Choiceland. Claims were staked in 1955 and 1956 on the basis of magnetic deviations, observed in the past by pilots flying over the area. Ground geophysics, and later airborne geophysics, showed a complex of magnetic anomalies and two in particular have been drilled. These are the Choiceland anomaly (5a) and the Kelsey Lake anomaly (5b).

The Choiceland anomaly was drilled between 1957 and 1959, and shown to consist of two bodies. A shaft pilot hole was cored in 1965 though a shaft was never constructed. The iron formation of highly inclined bedded magnetite-quartz was encountered at about 600 m and continued to more than 900 m depth. Based on this 300 m figure, on a strike length of 900 m and on an average width of 120 m, the main body would contain some 150 million tonnes of ore grading approximately 28 percent iron. A further 50 million tonnes is indicated for the second body, some 5 km to the northeast.

The Kelsey Lake anomaly is 30 km northeast of the Choiceland one. It was examined and drilled in 1975. Indicated reserves are in the order of 300 million tonnes, in a body 150 m wide, with a strike length of 3 km, starting at 550 m depth, and continuing for at least 300 m. The ore grade averages 30 percent iron reaching up to 85 percent in places.

The aeromagnetic map of the area shows numerous other anomalies. Interestingly, the Kelsey Lake anomaly extends to the east for about 8 km, then turns south near the town of Love and the Love anomaly runs south for 35 km. It would seem reasonable to assume that other bodies of iron ore must exist in the area.

There is another interesting occurrence 160 km south-east of Choiceland (5c). An exploratory well for petroleum, the Miami Hudson Bay No. 1 Nut Mountain well, drilled into magnetite at 1191.8m

and continued in it for 32 m before stopping. No other details of the deposit are known.

Mercury

Rumours of native mercury occurring in the Buffalo Narrows area were investigated by a party from the University of Regina in 1972 (Parslow, pers. comm.). A small quantity of native mercury was indeed found in muddy sediment in the bottom of a trench at Fleury Point (6), which abuts the narrows near the south end of Peter Pond Lake. This area has previously been investigated as the site where bituminous sands occur in the till. Kupsch (1954) reported various trenches in the area and did some trenching himself, but neither he nor previous authors reported the occurrence of mercury.

There are several obvious questions. Is this a spill and if so, who would be carrying mercury around in that area? Suggestions of a gold prospector or a photographer would seem to place the time of the spill many years back - and as mercury evaporates in the atmosphere it would have to have been below the water table all that time. With its high specific gravity, why would it not sink out of reach? If the occurrence is natural, how has it accumulated? Are exhalations of mercuric compounds rising into a reducing environment and being converted to the metal?

Further speculation, though interesting is futile without more thorough investigations. It would be interesting to know the size of the occurrence (or occurrences) and the nature of the substrate.

Other Considerations

Metallic mineral occurrences close to, but outside Saskatchewan, might well extend into the province. Such a case is exemplified by the deposit of nickel-copper ore presently being defined in Manitoba at Namew Lake. This deposit is in the Precambrian beneath Ordovician carbonates and very close to Saskatchewan's eastern border.

Over and above all the previous discussion, there is no reason that metallic ores present on the shield should be absent under the sedimentary cover. So, unless it is considered unique, an ore body like that at Rottenstone should have a counterpart somewhere. The Rottenstone ore is nickel and copper-rich with small amounts of platinum, palladium, gold, silver, lead and zinc. Exploration for platinum and its associates is also being conducted around an anorthosite body east of the Clearwater River Valley. Similar prospective situations might well exist south of the shield edge.

Conclusion

In conclusion, metallic mineral occurrences in or under the Phanerozoic rocks of Saskatchewan range from large deposits, through visible mineralization, to geochemical anomalies. Some of these, given the right circumstances, could become economic. Other occurrences remain to be found, some of which, in their turn, may prove to be economically viable.

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The Dawson Bay Formation (Devonian) in Southeastern Saskatchewan (Update)

by D.M. Lane

Lane, D.M. (1987): The Dawson Bay Formation (Devonian) in southeastern Saskatachewan; in Summary of Investigations 1987; Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

This study, commissioned in 1986, entails mapping of the subsurface Middle Devonian Dawson Bay Formation in the oil-producing area of southeastern Saskatchewan. The study area covers Townships 1 to 17 inclusive from the Manitoba border west to and including Range 2 west of the Third Meridian, and overlaps a portion of an area reported on by the author in 1959 (Fig. 1).

Previous department studies of the Dawson Bay Formation have been restricted to the potash-producing areas of the province. The most current is that of Dunn (1982).

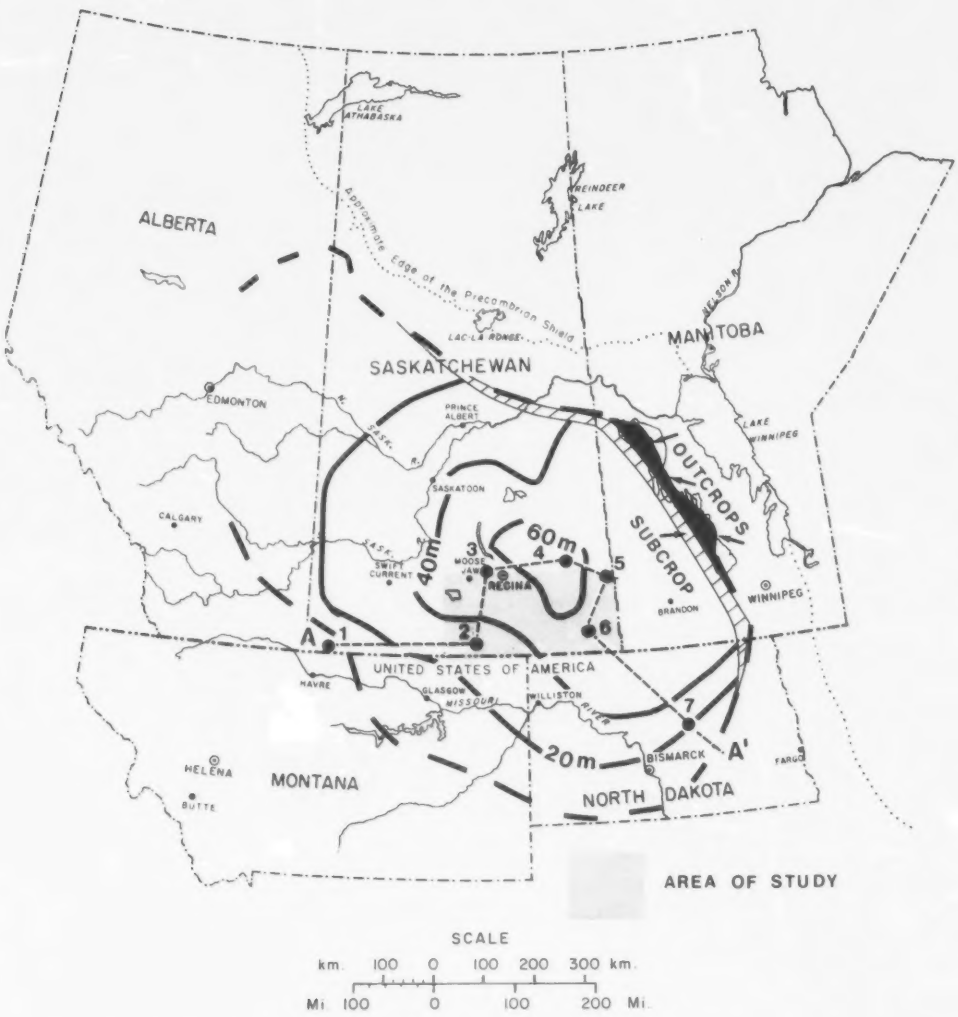
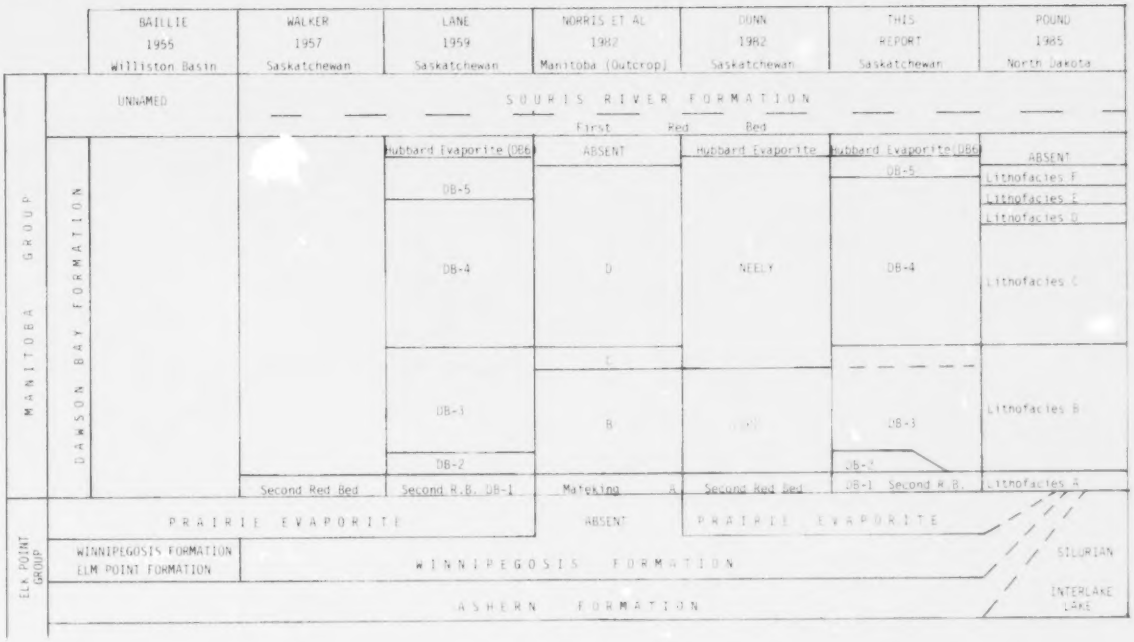


Figure 1 - Location map of the study area showing the distribution of the Dawson Bay strata. Contour interval 20 m.

Table 1 - Development of Middle Devonian Nomenclature



Scope of Work Completed to Date

The mapping of the Dawson Bay Formation in the study area includes examination of borehole data to interpret depositional history, diagenesis, structure, salt-solution and basin tectonics. Seismic and gravity surveys have not been considered to date.

Isopach maps of the basal First Red Bed of the Souris River Formation, the Dawson Bay Formation carbonate unit, the basal Second Red Beds of the Dawson Bay Formation, net halite of the Prairie Evaporite Formation and the Winnipegosis Formation, as well as structure contour maps on the tops of the Dawson Bay and Ashern Formations, have been prepared in preliminary form. Cross-sections have been prepared and drafted. A porosity-salt plugging map of the Dawson Bay carbonates is in preparation.

Nomenclature

Table 1 shows the development of nomenclature pertaining to the Dawson Bay Formation. The proposed Dawson Bay nomenclature basically follows that introduced by the author in 1959 (Lane, 1959).

Regional Stratigraphy

The location map (Fig. 1) shows the regional thickness, subcrop area, outcrop area and depositional edge of the Dawson Bay Formation, as well as the line of section used to illustrate the regional stratigraphy of the Dawson Bay Formation in the Williston Basin area (Fig. 2).

Regional Structure Map and Section

The regional structure contour map of the top of the Dawson Bay Formation (Fig. 3) shows the top of the formation rising from its maximum subsea depth of over 3000 m below sea level in northwestern North Dakota to less than 500 m below sea level in the northeastern portion of the study area. The maximum depth reached at the Saskatchewan - North Dakota border is slightly over 2000 m near the northwest corner of North Dakota.

The structure contour map shows the general location of the major structural features that may control oil migration from downdip North Dakota/ Montana Paleozoic formations, of which fourteen produce oil over the Nesson Anticline. The locations of production of Type 1 (Winnipeg Oil, Dow, 1974) indicated by a "W" are also shown on the map. Brown and Brown (1987) delineate a northwesterly and northeasterly set of lineament zones for Paleozoic rocks in Montana and North Dakota. The trends of these lineaments do not correspond in location with those of Dow; however, the directions of the lineaments are similar and are interpreted to extend into the study area.

During the past year, Dawson Bay and Souris River oil discoveries have been made some 24 km

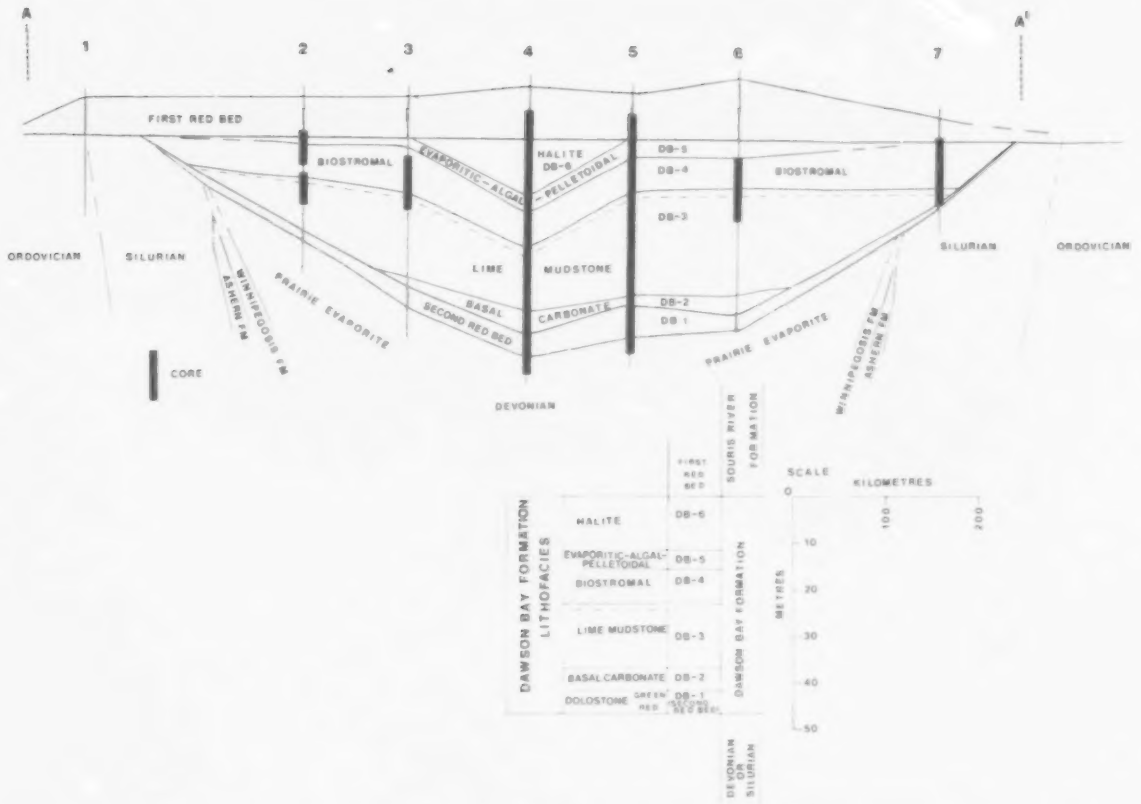


Figure 2 - Regional stratigraphy of the Dawson Bay Formation. Well names and locations as follows: 1) Mobile Oil Cypress Lake X 10-2, Lsd. 10-02-05-30W3; 2) Imperial Garville 8-23-3-24, Lsd. 08-23-03-24W2; 3) Sohio Canadian Devonian Stony Beach No. 1, Lsd. 04-16-18-23W2; 4) Winsal Beaverdale 3-32, Lsd. 03-32-26-07W2; 5) P.C.S. Rocanville 13-22-17-30, Lsd. 13-22-17-30W1; 6) BA Canadian Devonian Quinn 9-34X, Lsd. 09-34-03-04W2; 7) John Lueth No. 1, SE.SE, Sec. 27, Twp. 146N, R73W.

(15 miles) north of previous U.S. production and within 29 km (18 miles) of the Saskatchewan border (Dolphin Dawson Bay oil field). This has doubled the number of producing Dawson Bay wells in North Dakota.

Initial production from the discovery well in this field flowed at rates in excess of 1,500 bbls. per day on preliminary production tests. Souris River production from a well in the same field was reported as being between 80 and 100 bbls. of oil per day (Montana Oil Journal, June 11, 1987).

Hydrocarbon shows from the Dawson Bay Formation in Saskatchewan include recovery of 20 m (65 feet) of oil and salt water cut mud from DST #6 in the Newman No. 12 (Lsd. 12-29-2-2 W2) well.

Dawson Bay, Devonian and Lower Paleozoic Hydrocarbon Potential

A composite interpretive map (Fig. 4) is presented in an attempt to show the possible relationship between the known Dawson Bay and other Devonian and Lower Paleozoic hydrocarbon occurrences, fault tectonics, solution trends, drill-stem test recoveries and Winnipegosis thickness.

The basic interpretive model used is that the majority if not all of the Devonian and Lower Paleozoic hydrocarbon accumulations occurring in the study area were generated in the deeper regions of the Williston Basin. These hydrocarbons migrated updip into the study area by a combination of spillage from downdip traps (Nesson Anticline) and repeated structural movement which periodically reopened northwestward and northeastward fault/fracture patterns.

Potential updip porosity pinchout traps resulted from the removal of halite from the halite-plugged carbonates by formation waters associated with salt solution activated by basin tectonics and amplified by Winnipegosis carbonate "pinnacles". Movement along the interpreted fault traces (from the Ashern Structure Contour map) would have to represent total movement from original deposition to the present.

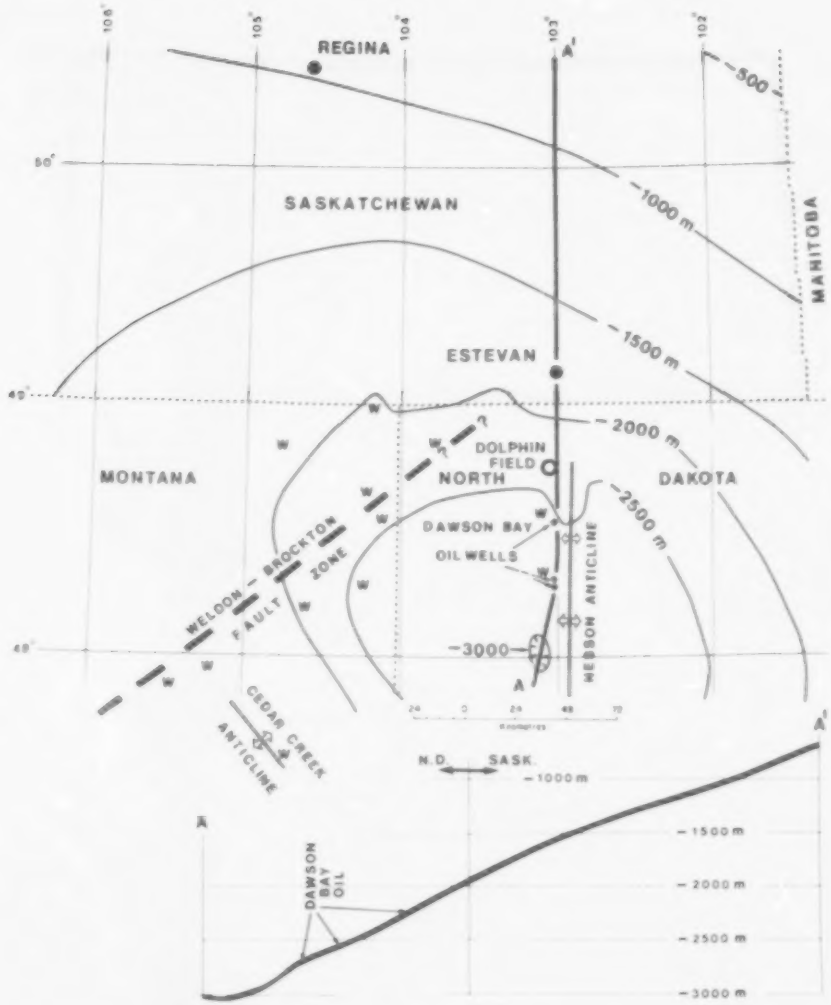


Figure 3 - Regional structure map and section on the top of the Dawson Bay Formation.

However, it is herein contended that movement along the fault traces in many cases commenced or was reactivated during Winnipegosis carbonate deposition and that many Winnipegosis "pinnacles" or mounds developed as linear features on the uplifted sides of fault blocks. Fragmental debris probably covered the fault scarps and reactivation provided the necessary access for hydrocarbons to accumulate in the Winnipegosis "reefs" where the overlying halites are largely unaffected. Where the faulting was more severe, formation waters were provided access to halites of the Prairie Evaporate.

It is therefore suggested that the "pinnacle" reef buildups often mark the edges of uplifted blocks. This interpretation is supported by the (northeasterly) linear solution trends . Repeated movement along "faults" provided access for formation waters and the migration of hydrocarbons into the overlying Devonian carbonates in the areas of "spot" removal of Prairie Evaporite halites over these reefs.

The absence of hydrocarbons in the pinnacle reefs where halites of the overlying Prairie Evaporite are absent indicates that any seal developed in these reefs was breached and any hydrocarbons that might have been previously trapped were released to the overlying Devonian carbonates. Migrating hydrocarbons in these areas are expected to be trapped in updip porosity pinchout traps (partial removal of salt plugging) in the Dawson Bay Formation, the Davidson Member of the Souris River Formation and possibly the Duperow Formation. The repeated porous carbonate/ anhydrite sequences in the Duperow should provide

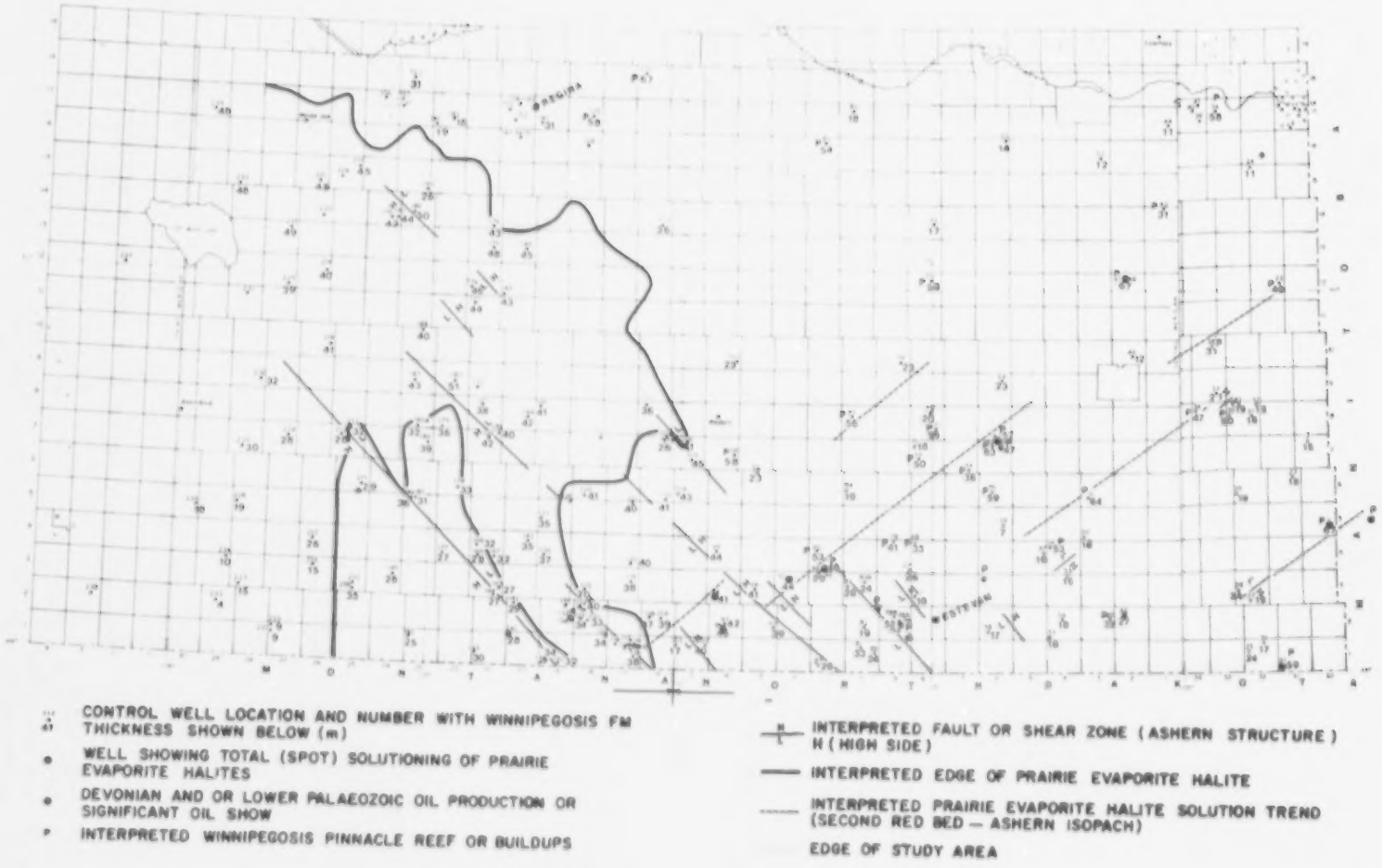

CONTROL WELL LOCATION AND NUMBER WITH WINNIPEGOSIS FM THICKNESS SHOWN BELOW (m)
WELL SHOWING TOTAL (SPOT) SOLUTIONING OF PRAIRIE EVAPORITE HALITES
DEVONIAN AND OR LOWER PALAEOZOIC OIL PRODUCTION OR SIGNIFICANT OIL SHOW
INTERPRETED WINNIPEGOSIS PINNACLE REEF OR BUILDUPS
INTERPRETED FAULT OR SHEAR ZONE (ASHERN STRUCTURE) H (HIGH SIDE)
INTERPRETED EDGE OF PRAIRIE EVAPORITE HALITE
INTERPRETED PRAIRIE EVAPORITE HALITE SOLUTION TREND (SECOND RED BED — ASHERN ISOPACH)
EDGE OF STUDY AREA

Figure 4 - Composite interpretive map.

numerous potential traps for any migrating hydrocarbons.

Oil trapped in the Birdbear Formation in the Kisbey field over a breached "pinnacle" reef suggests a structure related to the dissolution of the underlying Prairie Evaporite. Additional oil accumulations in the Birdbear carbonate are likely to exist. The vertical block fracture patterns interpreted in this study can be projected to the deeper Lower Paleozoic Formations and may assist in the location of new Ordovician hydrocarbons in the area. In the study area, only one Ordovician oil well is producing, whereas over 200 oil wells are producing from the Ordovician in North Dakota and Montana in the twelve townships immediately south of the study area.

The discovery of world class Saskatchewan Devonian Winnipegosis oil marks the beginning of a new era for petroleum exploration in the province. The current drilling stimulated by the Winnipegosis discoveries should lead to oil discoveries in formations that have not produced hydrocarbons in Saskatchewan to date.

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Regional Stratigraphic Correlation and Lithology of the Jurassic, Wapella - Moosomin Area, Southeastern Saskatchewan

by L.K. Kreis

Kreis, L.K. (1987): Regional stratigraphic correlation and lithology of the Jurassic, Wapella - Moosomin area, southeastern Saskatchewan; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

The study of the oil-prone Jurassic section in the Wapella - Moosomin area was initiated in June of 1986. The focus of the study is to develop a depositional model by a detailed study of all available core, geophysical well logs and, where necessary, drill cuttings.

This paper presents a regional stratigraphic correlation for the Jurassic between type and study areas (Fig. 1), and introduces the dominant lithologies encountered in core taken from the undifferentiated Middle Jurassic (i.e., Shaunavon - Upper Gravelbourg equivalent) section in the Red Jacket - Moosomin localities (see section in accompanying map package).

Stratigraphy

The west-east cross-section (in accompanying map package) shows the correlation of Jurassic strata between the type area in southwestern Saskatchewan (as defined by Milner and Thomas (1954)) and the presently active petroleum exploration area of the southeast. In particular, it demonstrates the correlation of the type section for the Shaunavon and Gravelbourg Formations at Eastend Crown No. 1 (15-11-6-20W3) with the equivalent section in the study area. Note the rapid and pronounced facies changes over this interval east of well 10 on the cross-section, leading to an arbitrary cutoff being made for Shaunavon and Upper Gravelbourg correlation between wells 10 and 11 . However, it appears that correlation of Lower Gravelbourg dolomitic limestone strata may be possible for some distance further east.

The Lower Watrous Member of the Watrous Formation pinches out against the Mississippian unconformity between wells 13 and 14 in the east. The Lower Watrous is overlapped by Upper Watrous in well 14.

The Lower Gravelbourg Member also exhibits pronounced thinning and eventual pinchout against Upper Watrous strata between wells 12 and 13 in the eastern portion of the cross-section. In wells 13 and 14, the Lower Gravelbourg appears to be absent and is overlapped by strata equivalent to the Shaunavon and Upper Gravelbourg.

Earlier workers such as Vigrass (1952), Stott (1955) and Christopher (1984) suggest that the top of the lower Gravelbourg is disconformable. Stott (1955) cites as evidence distinctive changes in lithology at this contact. Vigrass (1952) records the presence of a zone of bluish chalcedony at the contact and the variable thickness of the Lower Gravelbourg.

Christopher (1984, p.90) observes that a sandy facies overlying a hidden unconformity exists in the upper half of the Upper Gravelbourg Member as far west as longitude 105°W. He suggests that channels have truncated the underlying units of the Upper Gravelbourg and, as one approaches the arch (unamed in the paper) along longitude 102°W, even the Lower Gravelbourg Member has been removed. This upper sandy facies then disconformably overlies the Upper Watrous.

Work done to date suggests that there is no recognizable Lower Gravelbourg section present in the study area. The evidence cited by earlier workers for the presence of a disconformity (bluish chalcedony, variation in Lower Gravelbourg thickness areally) has also been observed to the southwest of the study area. The author believes this to show that the Lower Gravelbourg thins northward due to a combination of depositional onlap and an apparent post-Lower Gravelbourg erosional event in this the northeastern margin of the Williston Basin. The top of the Lower Gravelbourg appears to be disconformable for a considerable distance beyond the study area.

Correlation with strata in the type area has also permitted differentiation in the study area between the Rierdon Formation of the Vanguard Group and the Shaunavon-equivalent strata. In the type area, there is sufficient variance to make a pick between the rather uniform resistivity and other log signatures for the calcareous shale of the lowermost Rierdon beds and the generally sandy limestones of the uppermost Shaunavon beds. However, travelling east of the arbitrary cutoff (between wells 10 and 11) on the cross-section, there is an increasing amount of clay in the uppermost Shaunavon equivalent sandstone beds. This results in much less variance between log signatures of the Rierdon and uppermost Shaunavon-equivalent beds, and the pick becomes more tentative.

Christopher (1964) presents an exhaustive discussion of the Rierdon/Shaunavon contact in southwestern Saskatchewan, and places the contact at the base of a thin basal sandstone unit with abundant well-worn Gryphae nebrascensis and other pelecypod shell material. This basal Rierdon sandstone unit appears to be quite similar in lithology and log character to

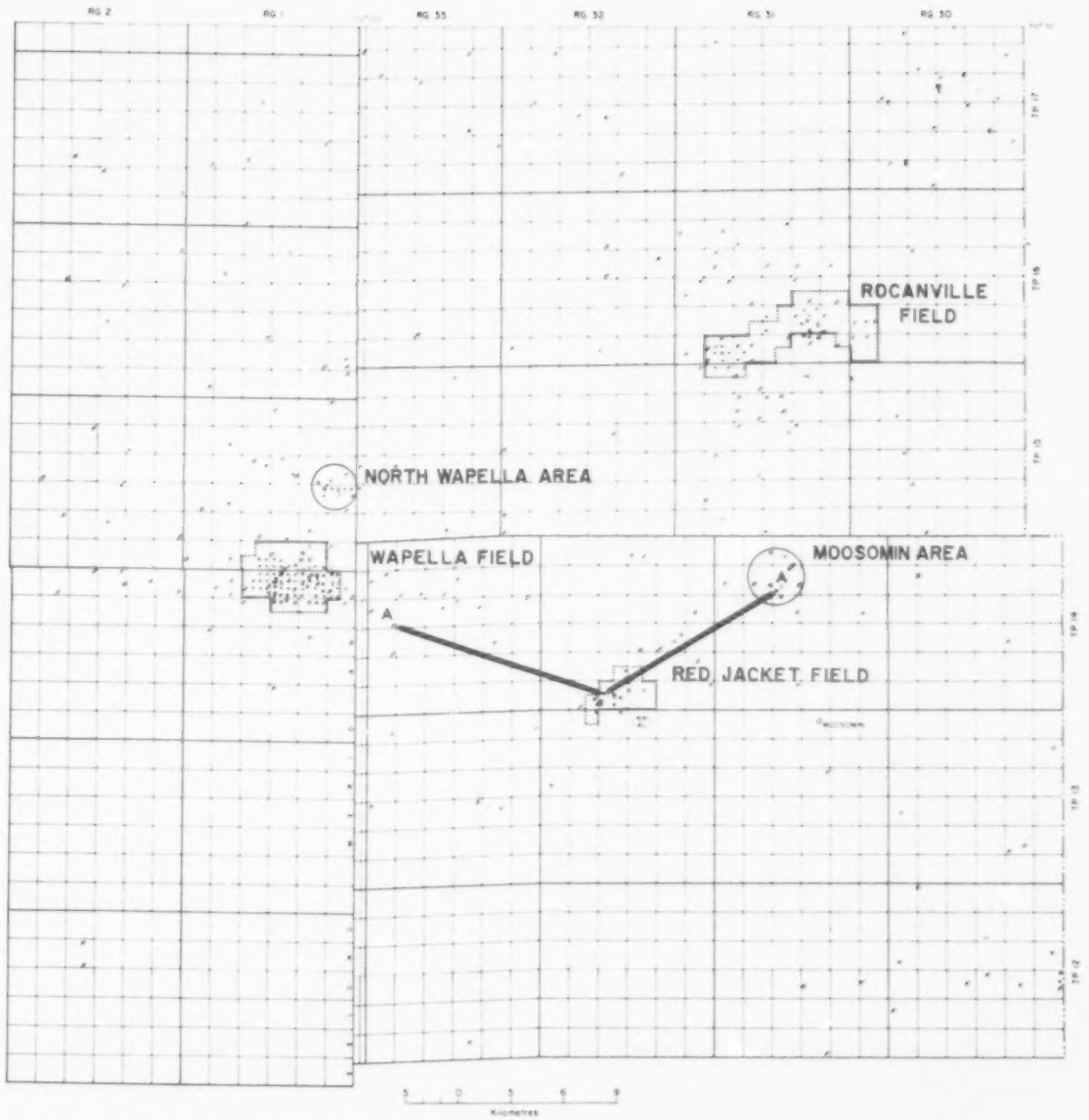

Figure 1 - Study area showing main petroleum producing localities and position of cross section A-A' in Fig. 2.

an apparent basal Rierdon sandstone unit present in some wells in the present study area. In effect, the base of the Rierdon (i.e., lowermost Vanguard) is placed by Christopher (1964) at the first appearance upwards of G. nebrascensis. In a later publication, Christopher (1966) revises some upper Shaunavon picks and suggests that there may have been an early invasion of G. nebrascensis from the north leading to the presence of G. nebrascensis in his uppermost U3 unit of the Upper Shaunavon in some wells in the northern portion of his study area.

Similarly, in the present study area, it may be impossible to determine whether the argillaceous, fossiliferous (G. nebrascensis-rich), calcite-cemented sandstone belongs as a time-rock unit to the Rierdon. As in the southwest, it may represent an early invasion of G. nebrascensis during Upper Shaunavon time.

Well 2 on Fig. 2 illustrates the log response of this well-worn G. nebrascensis-bearing sandstone unit and the contact between the Rierdon and the Upper

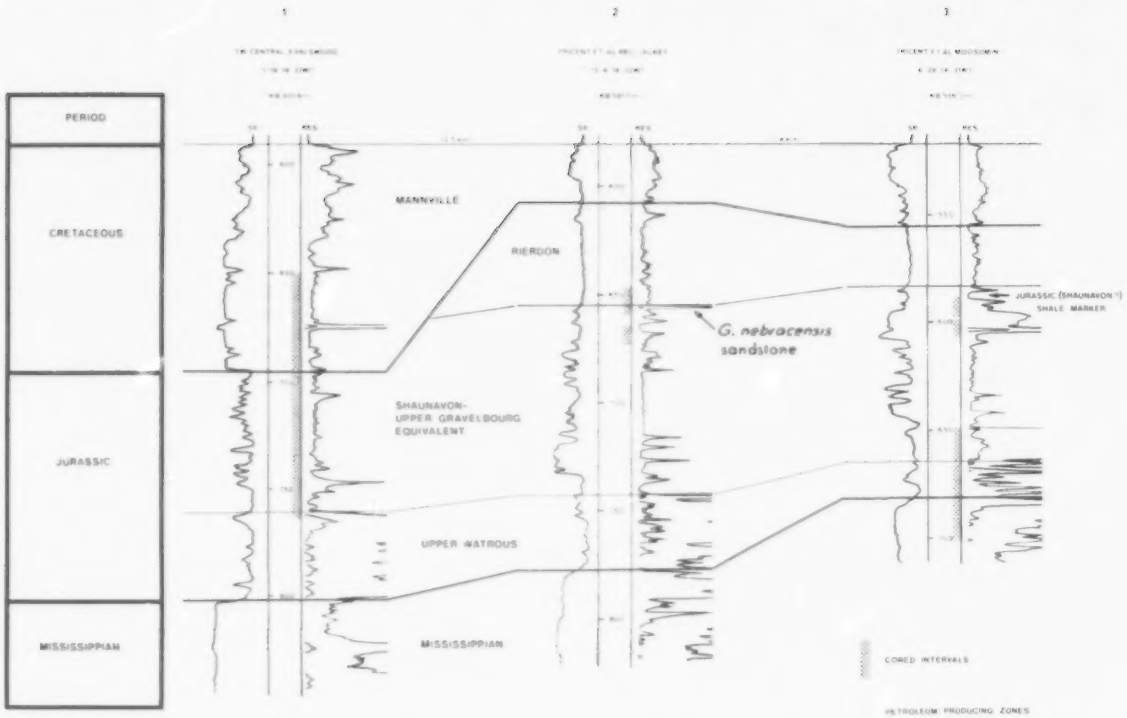

Figure 2 - Cross-section A'A' showing cored intervals exhibiting the dominant lithologies encountered in core in the study area and described in Appendix A. Also shown are zones of present petroleum production in the Red Jacket and Moosomin localities.

Shaunavon equivalent. The top of this sandstone unit defines the top of the Shaunavon - Upper Gravelbourg equivalent interval in this well. A detailed description from core, including the apparent contact interval, may be found in Appendix A.

Since it is not possible to distinguish on geophysical logs the known G. nebrascensis-bearing sandstone from other sandstone which may be Upper Shaunavon-equivalent, the author chooses to include the G. nebrascensis-bearing sandstone in the Upper Shaunavon-equivalent interval, realizing that this sandstone unit may belong to the Rierdon.

Where no sandstones are developed, calcareous shales of the Rierdon rest upon sandy shales, shaly sandstones or interlaminated shales and argillaceous sandstone beds of the Upper Shaunavon equivalent, all of which are calcareous. This results in little contrast in geophysical logs between the Rierdon and the underlying beds. In these instances, careful geophysical log correlation with wells that have contrasting Upper Shaunavon-equivalent sandstones, or correlation to the cored section is desirable. Picks made away from the control wells must be considered as tentative.

Occasionally, thin, very poorly developed, poorly sorted, highly argillaceous sandstones occur near the base of the Rierdon. They rarely have enough lithologic variability to be seen on a geophysical log and are thus unlikely to be included with the generally sandier underlying Upper Shaunavon lithologies.

The cored interval between 653.1 and 653.3 m (and likely most of the missing core between 653.3 and 655.0 m) of well 12-4-14-32W1 (Appendix A), provides an example of such a sandstone which cannot be distinguished from the calcareous shale of the Rierdon on the geophysical log (Fig. 2, well 2). In addition, this sandstone overlies the G. nebrascensis-rich sandstone discussed above and is separated from it by a 10 cm (655.1 to 655.2 m) calcareous mudstone with abundant G. nebrascensis and one 3.5 cm long almost complete belemnite guard. Belemnites are common in the Rierdon and have never been reported in the Upper Shaunavon. This would place the 10 cm thick calcareous mudstone and the overlying sandstone within the Rierdon.

Lithologic Descriptions

Although a continuous core through the entire section does not exist in the study area, a general representation of lithologies encountered can be made by selection of various cores from different stratigraphic intervals. The cored intervals used are indicated on the cross-section in Fig. 2 and are described in Appendix A. This cross-section also illustrates the zones of current petroleum production in the Red Jacket - Moosomin locality.

The cored intervals in well 2 (Fig. 2) exhibit the Rierdon/Shaunavon Upper Gravelbourg equivalent contact previously discussed. This well also seems to provide evidence for a diastemic break at 666.5 m between the medium grey claystone (which is informally referred to as the Jurassic (Shaunavon?) shale marker) and the underlying interlaminated claystone and sandstone, as the claystone shale marker infills a significant mud-crack in the bed below. Essentially, the cored interval below the claystone marker is a sequence of commonly bioturbated, greenish-grey sandstones and shales.

This Jurassic (Shaunavon?) shale marker bed is the most widespread correlatable lithologic unit in the study area, providing a useful datum within the Shaunavon-Upper Gravelbourg sequence. However, a Mesozoic erosional event has removed the unit in much of the north half of the area, and locally in and around the Wapella field in the south half.

The uppermost cored interval in well 3 (Fig. 2) again covers the medium grey Jurassic (Shaunavon?) shale marker and the underlying sequence of commonly bioturbated greenish-grey sandstones and shales. However, oil-saturated sandstone occurs between 594.8 m and approximately 600.0 m. This, a friable, very fine to fine-grained, clear quartz, subangular to rounded, well-sorted, zone is the primary petroleum target in the Red Jacket-Moosomin locality.

Another core taken between 649.0 and 702.0 m in well 3 penetrates a sandy (up to 50 percent very fine to fine-grain clear quartz), oolitic, glauconitic limestone unit between 649.0 and 663.7 m of the Shaunavon-Upper Gravelbourg section. This unit which is found in a number of localities in the study area, commonly exhibits very poor porosity and appears to have little or no reservoir potential. However, local porosity zones resulting from apparent dissolution of the carbonate matrix can be seen between 649.9 and 652.5 m in core from well 3 (Fig. 2). Well 11-4-14-32W1 from the Red Jacket field not only produces from the primary petroleum target but also from a basal unit which appears to correlate with the sandy, oolitic, glauconitic limestone described here.

Between 663.9 and 664.1 m, an 18 cm bed of highly argillaceous poorly-sorted sandstone with abundant pebble-sized, rounded to well-rounded chert appears to represent a transitional unit underlying the oolitic limestone.

This argillaceous sandstone unit is underlain by a 1.0 m thick conglomerate consisting of subangular to rounded clasts of dolostone, lesser chert and minor scattered quartz. In the opinion of the author, this conglomeratic unit represents a regolith of uppermost Upper Watrous strata and can be cited as evidence for exposure at this surface. The author believes the disconformity here to be contiguous with the previously discussed disconformity on top of the Lower Gravelbourg to the southwest of the study area.

The remainder of this cored interval consists of a 16 m interval of Upper Watrous with some poor recovery of Mississippian strata. The interbedded anhydrite, dolostone and dolomitic mudstone of the Upper Watrous unconformably overlies solution-pitted, anhydrite infilled, oil-stained Mississippian limestone.

The upper Watrous is moderately brecciated, displaying fractures infilled by secondary gypsum. It has been suggested that hydration/dehydration of anhydrite can provide a chemical mechanism for brecciation (J.E. Christopher, pers. comm., 1987). The arguments presented above in support of Upper Watrous exposure and disconformity at its upper contact would lend support to such a chemical process.

Well 1 (Fig. 2) exhibits a cored interval roughly spanning the middle and all of the lower portion of the Shaunavon-Upper Gravelbourg equivalent study section. Core recovery over the Jurassic section of this wireline hole is poor and scattered over a number of short segments. Nevertheless, it is one of the most complete and continuous cores in the study area.

In this well, the Mesozoic erosional event has removed the Jurassic (Shaunavon?) shale marker. The unconformity surface here at 2278 ft. (694.3 m) is immediately overlain by the Cretaceous Mannville Formation. The lower 5 ft. (1.5 m) of the Mannville (2273-2278 ft. (692.8-694.3 m)) is described in Appendix A.

The lithology of the middle portion of the study section in well 1 comprises a sequence of moderately to poorly sorted sandstones, interbedded with siltstones and shales. Contacts are mostly gradational but not much observed. The sediments seem to have been deposited under low energy conditions.

The lower marine unit of oolitic, glauconitic limestone found between 649.0 and 663.7 m in well 3 is not well developed in well 1; nevertheless a highly argillaceous limestone bed with minor oolite and glauconite occurs in well 1 between 2462 and 2464 ft. (750.4 and 751.0 m), near the top of a much thicker sequence of shales. This unit appears

to be equivalent to the oolitic glauconitic limestone in well 3.

A 0.3 m (1 ft.) thick bed of dolomite and anhydrite rubble from the Upper Watrous is encountered at 2496 ft. (760.8 m). The disconformable contact between the Shaunavon-Upper Gravelbourg equivalent and the Upper Watrous is poorly preserved in this well but shows more clearly in well 1.

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Appendix - Core Descriptions

The following core descriptions are for wells 1 to 3 in Fig. 2. Core depths have been adjusted to match geophysical log picks.

The grading scale for grain size of sandstone is based on the Wentworth scale as follows:

Category	Grain Diameter
Very coarse grained	- 2 to 1 mm
Coarse grained	- 1 to 0.5 mm
Medium grained	- 0.5 to 0.25 mm
Fine grained	- 0.25 to 0.125 mm
Very fine grained	- 0.125 to 0.06 mm

The sorting classification used follows Payne (1942):

Well sorted	- 90 percent in 1 or 2 size classes[1]
Moderately sorted	- 90 percent in 3 or 4 size classes[1]
Poorly sorted	- 90 percent in 5 or more size classes[1]

[1] of the Wentworth scale

The colour chart used was that of the Geological Society of America (second printing, 1951).

The term laminae refers to layers less than 1 cm in thickness, while bed refers to layers 1 cm thick or greater.

The following terms are used as a measure of mineral abundance:

Abundant	- greater than 10 percent
Minor	- 1 to 10 percent
Trace	- less than 1 percent

Well 3 (Fig. 2): Tricent et al. Moosomin 4-28-14-31W1

K.B: 556.0 m
Shaunavon-Upper Gravelbourg equivalent top ..... 583.0 m
Upper Watrous top ..... 665.1 m
Mississippian top ..... 681.5 m
Cored intervals: 588.5-597.5 m; 599.0-607.0 m; 649.0-702.0 m.

JURASSIC:

Shaunavon-Upper Gravelbourg Equivalent

588.5-589.6 (Rec. 1.1 m)
Claystone: medium grey (5N6), slabby parting, weakly calcareous, slightly bentonitic, abundant small (<1 cm average) pelecypods Pleuromya simplex(?) and P. oblongata(?) occur in thin 2-3 mm pavements. Lower 15 cm grades upwards from a highly interlaminated micaceous siltstone/ claystone, becoming bioturbated and sandy (very fine grain) over lower 5 cm. Lower contact poorly preserved but appears to be sharp.

589.6-591.3 (Rec. 1.7 m)
Sandstone and Mudstone: Bioturbated mottled greenish grey (5GY6/1) mudstone and very light grey (N8) sandstone. Sandstone is hard, composed of very fine grain clear quartz, subangular to subrounded, well sorted, well cemented with calcite, minor mica, minor pyrite, slightly silty. Mudstone component is calcareous, with swelling clays and is locally very sandy. The interval is highly bioturbated giving it a mottled appearance. Locally, bioturbation appears to have homogenized the sediments. Lower contact sharp, defined by oil-stained contact of underlying sandstone.

591.3-592.1 (Rec. 0.8 m)
Sandstone: pale yellowish brown (10YR6/2) to yellowish grey (5Y8/1), friable to moderately cemented over upper 5 cm, very fine grain clear quartz, subangular to subrounded, moderately sorted, silty, minor mica. The interval becomes very silty, slightly bioturbated and interlaminated with argillaceous silt and mudstone over the lower 45 cm. Planolites is observed in the lower 35 cm. Upper 40 cm is oil stained, exhibiting good to excellent intergranular porosity. Lower contact gradational.

592.0-594.8 (Rec. 2.8 m)
Sandstone: light greenish grey (5GY8/1), hard, very fine to fine grain clear quartz, subangular to subrounded, poorly sorted, highly calcareous, argillaceous, silty, minor mica, minor pyrite, indeterminate carbonate grains up to fine grain size. Moderately to highly bioturbated. Weakly preserved remnants of inclined bedding up to 30°. Only slightly bioturbated over lower 20 cm with oil-stained interbeds. Lower contact gradational.

594.8-597.5 (Rec. 2.7 m)
Sandstone: dark yellowish brown (10YR4/2), friable, very fine to fine grain clear quartz, subangular to subrounded, well sorted. Excellent intergranular porosity, heavily oil saturated.

599.0-604.9 (Rec. 5.9 m)
Sandstone: dark yellowish brown (10YR4/2) to light grey (N7), friable to locally hard, very fine to fine clear quartz, subangular to subrounded, well sorted, minor mica, slightly argillaceous, very slightly to moderately calcite-cemented between 599.0 and 601.0 m. Becoming increasingly calcite cemented, silty and micaceous towards base with numerous less cemented breaks showing oil staining. The better cemented intervals exhibit thin argillaceous, micaceous, slightly carbonaceous interlaminations and the occasional grey mudstone drape. These intervals also seem to demonstrate a weak ripple bedding. Lower contact sharp, possibly scoured.

604.9-605.6 (Rec. 0.7 m)
Sandstone: light greenish grey (5GY 8/1) to greenish grey (5GY 6/1), friable to moderately consolidated, very fine to fine grain clear quartz, subangular to subrounded, moderately sorted, slightly to moderately calcite-cemented, slightly argillaceous, locally very silty. Some interlamination with very argillaceous silt and mudstone. Lower contact not preserved.

605.6-607.0 (Rec. 0.0 m)
Core missing.

649.0-663.7 (Rec. 14.7 m)
Limestone: very light grey (N8) to light grey (N7) and dark yellowish brown (10YR4/2), hard, locally up to 50 percent, very fine to fine grain clear quartz, subangular-rounded , up to 30 percent medium grain oolite(?) and other indeterminate carbonate grains, slightly silty, very slightly argillaceous, minor glauconite, trace of mica, minor chert, very fine cyrstalline calcite matrix. Oil-stained patches between 649.9 and 652.5 m exhibit fair intergranular porosity. Numerous microstyolites and the occasional poorly developed large (0.5 cm), silty, argillaceous, stylolite. Lower contact sharp.

663.7-663.8 (Rec. 0.1 m)
Limestone: light olive grey (5Y6/1), hard,

argillaceous, dolomitic, trace of chert, less than 5 percent floating very fine to fine grain quartz. Becomes highly argillaceous and sandy over lower 2 cm. Lower contact gradational.

663.8-663.9 (Rec. 0.1 m)
Sandstone: light olive grey (5Y6/1) and dark yellowish brown (10YR4/2), hard, very fine to fine grain clear quartz, subangular to subrounded, moderately well sorted, calcite-cemented, slightly argillaceous, trace of chert. Lower contact sharp.

663.9-664.1 (Rec. 0.2 m)
Sandstone: light olive grey (5Y6/1), hard, very fine to fine grain clear quartz, subangular to rounded, poorly sorted, silty, highly argillaceous, abundant coarse grain to pebble size, rounded to well rounded chert. Lower contact sharp, erosive and disconformable, incorporating weathered dolomite from below.

664.1-665.1 (Rec. 1.0 m)
Conglomerate: greyish blue (5PB5/2) and very pale orange (10YR8/2). This interval is comprised of coarse grain to pebble size subangular to rounded clasts of dolostone and chert with scattered quartz a minor component. Slightly sucrosic to cryptocrystalline dolomite matrix. Numerous oil-stained microfractures and oil-stained patches observed.

Upper Watrous

665.1-681.5 (Rec. 16.4 m)
Anhydrite, Dolostone and Dolomitic Mudstone: This interval is interbedded and multicoloured; very pale orange (10YR8/2) greyish blue (5PB5/2), light olive grey (5Y6/1) and greenish grey (5GY6/1). Interbeds of thick (up to 40 cm) greyish blue translucent anhydrite, very pale orange dolostone (up to 75 cm thick) and light olive grey to greenish grey dolomitic mudstone make up this interval. These interbeds are moderately brecciated with secondary gypsum infilling fractures. Much of the anhydrite present is nodular and coalescing. The interval between 679.6 and 680.9 m is red mudstone.

MISSISSIPPIAN:

681.5-685.0 (Rec. 3.5 m)
Anhydrite and Limestone: greyish blue (5PB5/2) translucent anhydrite, infilling voids within the very pale orange (10YR8/2) to greyish orange pink (5YR7/2) and pale yellowish brown (10YR6/2) limestone. The upper 2.5 m exhibits abundant black angular chert and chertified limestone fragments. Fractures are infilled with secondary gypsum. Oil staining in a few patches in lower half of interval.

685.0-702.0 (Rec. 8.0 m)
Limestone: very pale orange (10YR8/2) to greyish pink (10YR7/2) and moderate yellowish brown (10YR5/4). Approximately two-thirds of the interval between 689.0 and 702.0 m is missing.

Well 2 (Fig. 2): Tricent et al. Red Jacket 12-4-14-32W1

K.B: 581.1 m
Rierdon top ..... 607.0 m
Shaunavon-Upper Gravelbourg equivalent top ..... 655.2 m
Upper Watrous top ..... 742.4 m
Cored intervals: 646.7-659.0 m; 663.9-672.4 m

JURASSIC:

Rierdon

646.7-653.1 (Rec. 6.4 m)
Mudstone: light olive grey (5Y6/1), slabby parting hard, highly calcareous, minor disseminated pyrite, fossiliferous (belemnites, occasional pelecypod, ammonite fragments (Kepplerites?). Lower contact sharp.

653.1-653.3 (Rec. 0.2 m)
Sandstone: pale yellowish brown (10YR6/2), very fine to fine grain clear quartz, subangular to subrounded, poorly sorted, very silty, highly argillaceous, highly calcareous, abundant fine to medium grain size (up to 50 percent locally) ironstone "oolite", minor mica, minor pyrite, abundant broken-up well-worn Gryphaea nebrascensis and other pelecypod debris. Serpula exhibiting winding burrows up to 2 mm in diameter. Fair to poor intergranular porosity. Lower contact missing.

653.3-655.1 (Rec. 0.0 m)
Core missing.

655.1-655.2 (Rec. 0.1 m)
Mudstone: pale yellowish brown (10YR6/2), hard, slabby parting, calcareous, minor pyrite, abundant well-worn pelecypod fragments and occasional belemnite. Lower contact gradational.

Shaunavon-Upper Gravelbourg Equivalent

655.2-656.6 (Rec. 1.4 m)
Sandstone: light olive grey (5Y6/1), very fine to fine grain, clear quartz, subangular to subrounded, moderately sorted, calcite cemented, slightly to moderately silty, argillaceous, minor pyrite, trace of glauconite, abundance of broken and worn G. nebrascensis and other pelecypod shells. Mudstone break between 656.3 and 656.4 m. Lower two-thirds of interval less silty, less argillaceous and better sorted. Lower contact not present.

656.6-656.7 (Rec. 0.0 m)
Core missing.

656.7-657.0 (Rec. 0.3 m)
Sandstone and Mudstone: interlaminated. Sandstone is light olive grey (5Y6/1), moderately friable to hard, very fine to fine grain clear quartz, subangular to subrounded, well sorted, calcareous

over upper half, abundant patches (up to 3 cm across) of pyrite cement, micaceous, abundant small pelecypods (<1 cm) over upper 10 cm. One large (7 cm across) pelecypod at lower contact. Mudstone is medium grey (N5), sandy over upper 10 cm becoming increasingly argillaceous and bioturbated over lower 20 cm. Lower contact is sharp and somewhat irregular.

657.0-657.2 (Rec. 0.2 m)
Mudstone: greenish grey (5GY6/1), slabby parting, weakly calcareous, minor pyrite, abundant small (<1.5 cm) pelecypods, up to 10% very fine to fine grain subangular to subrounded floating quartz. Occasional micaceous silt laminations near top and base. Lower contact gradational.

657.2-658.0 (Rec. 0.8 m)
Sandstone and Mudstone: interbedded. Sandstone is very light grey (N8) to dark yellowish brown (10YR4/2) and mudstone is greenish grey (5GY6/1). Sandstone is very fine to fine grain clear quartz, subangular to subrounded, calcite cemented, minor mica, minor pyrite nodules. Calcareous mudstone component interlaminataed with calcite-cemented sandstone. Interbeds of mudstone up to 2 cm thick. Becomes increasingly bioturbated towards base. Sandstone interbeds are oil stained over lower 40 cm. Lower contact is gradational.

658.0-659.0 (Rec. 1.0 m)
Sandstone and Mudstone: bioturbated, mottled, very light grey (N8) sandstone and greenish grey (5GY6/1) mudstone. Sandstone is very hard, very fine to fine grain clear quartz, subangular to subrounded, calcite cemented, minor mica, minor pyrite, locally abundant oncolites and well-worn peleypod shell fragments. Mudstone break between 658.3 and 658.5 m. The interval is highly bioturbated giving it mottled texture. Lower contact is not present.

663.9-666.5 (Rec. 2.6 m)
Claystone: medium grey (N5), hard, slabby parting, weakly calcareous, slightly bentonitic, abundant small (1 cm average) pelecypods (possibly Pleuromya simplex and P. oblongota?) commonly found in thin (2 to 3 mm) pavements, minor pyrite (commonly found as nodules). Becomes increasingly interlaminated over lower 40 cm with micaceous, calcite-cemented silt to very fine grain subangular clear quartz. Moderately burrowed over lower 15 cm. Lower contact is sharp and irregular with the claystone infilling a 1 cm wide crack in the underlying bed.

666.5-666.9 (Rec. 0.4 m)
Claystone and Sandstone: interlaminated greenish grey (5GY6/1) claystone and very light grey (N8) sandstone. Claystone is hard, calcareous, minor mica and abundant small (1 cm average) pelecypods. Sandstone laminae are slightly micaceous, slightly silty, calcite-cemented, very fine to fine grain clear quartz. Moderately bioturbated. Lower contact sharp and irregular.

666.9-667.2 (Rec. 0.3 m)
Mudstone: greenish grey (5GY6/1), hard, slabby, highly calcareous, trace of mica, few small (<1 cm) pelecypods. Lower contact sharp and irregular.

667.2-668.1 (Rec. 0.9 m)
Sandstone: light greenish grey (5GY8/1), and greenish grey (5GY6/1) hard, very fine to fine grain clear quartz, subangular to subrounded, well sorted, well cemented with calcite, slightly argillaceous, trace of mica, trace of pyrite, abundant small (<1 cm) mostly broken-up pelecypods. The interval is intensely bioturbated. Interlaminations of greenish grey (5GY6/1) mudstone. Lower contact not well preserved but appears sharp.

668.1-668.9 (Rec. 0.8 m)
Mudstone and Sandstone: interbedded. Mudstone is greenish grey (5GY6/1), highly calcareous, exhibiting minor mica, minor pyrite, few small (<1 cm average) pelecypods and locally up to 30 percent floating grains of very fine to fine grain subangular clear quartz. Light greenish grey (5GY8/1) sandstone component is composed of very fine to fine grain, clear, subangular to subrounded, quartz. It is well cemented with calcite and slightly silty, with minor amounts of mica and pyrite. Between 669.2 and 669.3 m, sandstone dominates and charophytes occur. The entire interval is moderately to locally intensely bioturbated giving it a mottled texture. Lower contact is gradational.

668.9-670.0 (Rec. 1.1 m)
Sandstone and Mudstone: interlaminated. Sandstone is light greenish grey (5GY8/1), hard, composed of very fine to fine grain clear quartz, subangular to subrounded, moderately well sorted, silty, slightly argillaceous and calcite-cemented, with minor mica, minor to locally abundant pyrite, few poorly preserved small (<1 cm) pelecypods. Greenish grey (5GY6/1) mudstone interlaminations are calcareous with minor pyrite and up to 10 percent floating very fine to fine grain quartz. The entire interval is moderately bioturbated. Lower contact gradational.

670.0-670.6 (Rec. 0.6 m)
Claystone: greenish grey (5GY6/1), hard, slabby parting, calcareous, minor pyrite, trace of indeterminate fish(?) bone fragments. Lower contact sharp.

670.6-671.0 (Rec. 0.4 m)
Sandstone: yellowish grey (5Y8/1) to light greenish grey (5GY8/1), hard, very fine to fine grain clear quartz, subangular to subrounded, moderately argillaceous, silty, minor mica, trace of pyrite, sparse interlaminations of sandy mudstone. The interval is slightly to moderately bioturbated. Lower contact sharp.

671.0-672.4 (Rec. 1.4 m)
Sandstone: yellowish grey (5Y8/1) to light greenish grey (5GY8/1) and pale yellowish brown (10YR6/2),

moderately friable to friable, very fine to fine grain clear quartz, subangular to subrounded, calcareous, slightly to moderately argillaceous, silty to locally very silty, minor mica, trace of pyrite. Highly interlaminated with silty, micaceous, moderately to highly argillaceous sandy laminations. Becomes increasingly silty towards base. Pale yellowish brown (10YR6/2) oil-stained patches within numerous intervals of less argillaceous and calcite-cemented sandstone.

Well 1 (Fig. 2): TW Central Earlswood 1-19-14-33W1[1]

K.B: 1941 ft. (591.6 m)
Mannville top ..... 1939 ft. (591.0 m)
Shaunavon-Upper Gravelbourg equivalent top ..... 2278 ft. (694.3 m)
Upper Watrous top..... 2496 ft. (760.8 m)
Cored interval: 2133-2507 ft. (650.1-764.1 m)

CRETACEOUS:

Mannville

2273.0-2278.0 (692.8-694.3) (Rec. 0.3 m)
Sandstone: white (N9) to very light grey (N8), moderately friable, medium to very coarse, clear quartz, subrounded to well rounded, moderately sorted, moderately calcite-cemented, trace of carbonaceous fragments. Lower contact missing.

JURASSIC:

Shaunavon-Upper Gravelbourg Equivalent

2278.0-2283.0 (694.3-695.8) (Rec. 0.2 m)
Claystone: green grey (5GY8/1), hard, slabby parting, micaceous, slightly swelling clays, trace of pyrite. Occasional silt lamination. Lower contact missing.

2283.0-2284.0 (695.8-696.1) (Rec. 0.3 m)
Mudstone: yellow grey (5Y8/1), hard, slabby parting, calcareous, few small (2 to 3 mm) pelecypods. Sandstone dyke approximately 2 mm wide. Lower contact sharp and irregular.

2284.0-2285.7 (696.1-696.7) (Rec. 0.5 m)
Sandstone: yellow grey (5Y8/1), hard, very fine to fine grain clear quartz, subangular-subrounded, moderately sorted, slightly argillaceous, calcite-cemented, minor pyrite, minor indeterminate carbonate grains. Lower contact sharp and irregular.

2285.7-2287.0 (696.7-697.0) (Rec. 0.3 m)
Claystone: green grey (5GY6/1) to light olive grey (5Y6/1), hard, flaggy to slabby parting, slightly calcareous, slightly swelling clays, abundant small (<1 cm) pelecypods. Grades upwards from a silty, sandy mudstone over lower 20 cm. Lower contact gradational.

2287.0-2288.0 (697.0-697.3) (Rec. 0.3)
Sandstone: light olive grey (5GY6/1), hard, very fine to fine grain clear quartz, subangular to subrounded, moderately sorted, silty argillaceous, slightly calcareous, moderately bioturbated, minor pyrite. Lower 12 cm well cemented with calcite, abundant pyrite-cemented patches (<2 mm average). Lower contact sharp and irregular.

2288.0-2292.7 (697.3-698.8) (Rec. 1.5 m)
Mudstone: green grey (5GY6/1), hard, flaggy parting, slightly calcareous. Occasional silty, micaceous, very fine grain, subangular clear quartz lamination. Lower contact missing.

2292.8-2303.5 (698.8-702.1) (Rec. 3.3 m)
Sandstone: light greenish grey (5GY8/1) to greenish grey (5GY6/1), very fine to fine grain clear quartz, subangular to subrounded, poorly sorted, moderately hard, slightly argillaceous, very silty, abundant mica, minor pyrite. Laminated with highly argillaceous, micaceous sandy silt. Interlaminated mudstone and siltstone between 2295.5 and 2301 ft. (699.7 and 701.3 m). Upper 8 cm well cemented with calcite. Lower contact gradational.

2303.5-2309.5 (702.1-703.9) (Rec. 1.8 m)
Sandstone: light green grey (5GY8/1), friable, very fine grain clear quartz, subangular, moderately sorted, silty, slightly argillaceous, minor mica. Lower contact sharply defined by a 1.5 cm layer of pyrite-cemented sandstone.

2309.5-2314.0 (703.9-705.3) (Rec. 0.8 m)
Claystone: variegated, greenish grey (5GY6/1), pale yellowish orange (10YR8/6) to dark reddish brown (10R3/4), flaggy parting, hard, swelling clays. Lower contact missing.

2314.0-2321.3 (705.3-707.5) (Rec. 2.2 m)
Sandstone: yellowish grey (5Y8/1) to greenish orange (10YR7/4), hard, very fine to fine grain clear quartz, subangular to subrounded, moderately sorted, slightly argillaceous, calcite-cemented, silty, minor mica, minor pyrite nodules (<2 mm average), few indeterminate bone fragments. Low angle to high angle (up to 25°) planar bedding. Becomes more argillaceous and less indurated over lower 70 cm. Lower contact sharp, defined by a 5 cm pyritic sandstone, well cemented with calcite at base.

2321.3-2336.5 (707.5-712.1) (Rec. 4.6 m)
Sandstone: greenish grey (5GY6/1) and very light grey (N8), moderately friable, very fine grain clear quartz, subangular to subrounded, well sorted, silty, micaceous. Numerous laminae of highly argillaceous, silty, micaceous sandstone. Becomes

[1]This well was originally logged in feet, so the metric equivalents have been calculated to facilitate comparison with the other wells.

very calcareous between 2324.0 and 2328.0 ft. (708.7 and 709.4 m). Bioturbated between 2325 and 2327.5 ft. (708.6 and 709.4 m). Becomes interbedded/interlaminated with mudstone and highly argillaceous, glauconitic, highly silty sandstone over lower 5 ft. (1.5 m). Lower contact gradational.

2336.5-2342.0 (712.2-713.8) (Rec. 1.6 m)
Sandstone: very light grey (N8), very fine to fine grain clear quartz, subangular to subrounded, moderately sorted, slightly silty, minor mica. Becomes increasingly laminated with argillaceous silt and mudstone over lower 2 ft. (60 cm). Lower contact gradational.

2342.0-2348.0 (713.8-715.6) (Rec. 1.8 m)
Sandstone and Mudstone: interlaminated, very light grey (N8) sandstone and medium grey (N4) mudstone. Sandstone is poorly sorted, moderately friable, silty, locally argillaceous but is mainly composed of subangular to subrounded very fine to fine grain clear quartz with minor pyrite and a trace of carbonaceous fragments. Sandstone interlaminated with mudstone and very argillaceous, silty sand. Mudstone dominates over lower 1 ft. (0.31 m). Lower contact missing.

2348.0-2351.0 (715.6-716.5) (Rec. 0.8 m)
Sandstone: very light grey (N8), friable, very fine to fine grain clear quartz, subangular to subrounded, moderately sorted, highly silty over upper 1.5 ft (0.5 m), minor mica. Lower contact gradational.

2351.0-2355.0 (716.5-717.8) (Rec. 1.2 m)
Mudstone: medium dark grey (N6), slabby parting, hard, minor carbonaceous fragments. Contains laminae of highly argillaceous, micaceous siltstone to very fine grain clear quartz sandstone. Lower contact gradational.

2355.0-2358.5 (717.8-718.8) (Rec. 1.0 m)
Sandstone: yellowish grey (5Y8/1), moderately friable, very fine to fine grain clear quartz, subangular to subrounded, moderately sorted, moderately calcite-cemented, silty, slightly argillaceous, abundant mica, minor pyrite. Contains laminae with more highly argillaceous and silty sand over lower half. Lower contact gradational.

2358.5-2372.0 (718.8-723.0) (Rec. 3.2 m)
Sandstone and Mudstone: sandstone is yellowish grey (5Y8/1) with greenish grey (5GY6/1) mudstone interbeds. The sandstone is hard, very silty, slightly argillaceous with minor amounts of mica but is mainly composed of moderately sorted, subangular, very fine grain, clear quartz. The sandstone exhibits numerous silty, micaceous argillaceous laminations. The mudstone is quite laminated with highly argillaceous, micaceous, silty laminae. Sandstone beds range from 0.3 m to 0.9 m thick, while the mudstone interbeds vary from 0.3 m to 1.2 m thick. Lower contact missing.

2372.0-2379.0 (723.0-725.1) (Rec. 2.1 m)
Mudstone and Siltstone: mudstone is light olive grey (5Y6/1) with very light grey (N8) siltstone interbeds. The mudstone is hard, calcareous with slabby partings, minor mica, trace of carbonaceous fragments and many silty micaceous laminations. Siltstone interbeds are argillaceous, mica rich, sandy (up to 30 percent very fine grain clear quartz) with numerous laminae of mudstone. Mudstone beds range from 0.4 to 1.2 m thick, while siltstone interbeds range from 0.1 to 0.3 m thick. Lower contact gradational.

2379.0-2383.0 (725.1-726.3) (Rec. 0.5 m)
Sandstone: very light grey (N8), moderately friable, very fine to fine grain clear quartz, subangular to subrounded, moderately sorted, some argillaceous laminations, silty, minor mica, trace of pyrite, trace of carbonaceous fragments. Lower contact missing.

2383.0-2395.0 (726.3-730.0) (Rec. 2.7 m)
Mudstone: variegated, greenish grey (5GY6/1), medium grey (N5), moderate yellowish brown (10YR5/4) to pale reddish brown (10R5/4), slabby parting, hard, calcareous, exhibits slickensides. Some sandstone interbeds of poorly sorted, silty, micaceous, moderately calcareous, argillaceous, very fine to fine grain, subangular to subrounded clear quartz, with highly argillaceous, silty, micaceous laminae occurring between 2385.5 and 2386.0 ft. (727.1 and 727.3 m) and 2391.0 and 2392.0 ft. (728.7 and 729.0 m). Lower contact not present.

2395.0-2404.0 (730.0-732.7) (Rec. 1.2 m)
Sandstone: light grey (N7), friable, fine grain clear quartz, subangular to subrounded, well sorted, minor mica, slightly calcareous, slightly silty. Argillaceous laminations towards base. Lower contact not present.

2404.0-2415.0 (732.7-736.0) (Rec. 2.1 m)
Mudstone: variegated, greenish grey (5GY6/1), yellowish grey (5Y8/1), light olive grey (5Y6/1) to pale red (10R6/2), hard, slabby parting, moderately calcareous, trace of carbonaceous fragments, occasional slickensides. Highly fractured limestone interbed between approximately 2407.0 and 2408.0 ft. (733.6 and 733.9 m). Core exhibits poor quality and recovery. Lower contact missing.

2415.0-2424.0 (736.0-738.8) (Rec. 1.2 m)
Sandstone and Mudstone: sandstone is very light grey (N8) with greenish grey (5GY6/1) mudstone interbeds. Sandstone is moderately hard, comprised of very fine to fine grain clear quartz, subangular to subrounded, moderately to poorly sorted, moderately to highly argillaceous, slightly to locally calcite-cemented, moderately to highly silty, minor mica, trace of carbonaceous fragments. Locally contains numerous laminae of argillaceous silt and mudstone. Greenish grey mudstone component is hard, calcareous with minor pyrite and slabby partings. Upper half of interval bioturbated. Bed thicknesses are difficult to determine due to poor recovery. Lower contact missing.

2424.0-2431.0 (738.8-740.9) (Rec. 0.9 m)
Sandstone: light greenish grey (5GY8/1) to greenish grey (5GY6/1), hard, very fine to fine grain clear quartz, subangular to subrounded, poorly sorted, moderately calcite-cemented, moderately to highly silty, minor mica. Locally has common to numerous laminae of moderately to highly argillaceous sandstone and mudstone. Lower contact missing.

2431.0-2433.0 (740.9-741.5) (Rec. 0.6 m)
Claystone: greenish grey (5GY6/1), hard, flaggy parting, slightly calcareous, slickensides present. Lower contact sharply defined by abundant pyrite-cemented patches in underlying sandstone.

2433.0-2441.0 (741.5-744.0) (Rec. 1.1 m)
Sandstone: yellowish grey (5Y8/1), friable, very fine to fine grain clear quartz, subangular to subrounded, moderately sorted, minor mica, slightly silty. Lower contact missing.

2441.0-2443.0 (744.0-744.6) (Rec. 0.6 m)
Mudstone: light greenish grey (5GY8/1) to greenish grey (5G6/1), hard, slabby parting, calcareous, sandy (up to 20 percent very fine to fine grain clear quartz), minor mica, trace of pyrite, trace of carbonaceus fragments. Lower contact sharp, defined by 0.5 cm very sandy layer with large (up to 1 cm) pyrite crystals.

2443.0-2447.0 (744.6-745.8) (Rec. 0.6 m)
Mudstone: light olive grey (5Y6/1), hard, micaceous, trace of carbonaceous fragments, indeterminate bone fragments, fish teeth and scales. Becomes highly silty, micaceous and pyritic over lower half. Lower contact missing.

2447.0-2453.0 (745.8-747.6) (Rec. 0.9 m)
Sandstone: very light grey (N8), very hard, very fine to fine grain clear quartz, moderately sorted, moderately to highly calcite-cemented, silty, abundant mica, abundant pyrite. Highly laminated with argillaceous, micaceous laminae. Lower contact missing.

2453.0-2460.0 (747.6-749.8) (Rec. 1.4 m)
Siltstone: very light grey (N8) and light grey (N7), moderately hard, highly micaceous, locally abundant pyrite. Numerous laminae of highly argillaceous silt and mudstone. Becomes very silty, micaceous, calcite-cemented, very fine grain clear quartz sandstone with abundant argillaceous laminations and abundant pyrite. Lower contact missing.

2460.0-2482.0 (749.8-756.5) (Rec. 5.5 m)
Mudstone: light olive grey (5Y6/1) to medium dark grey (N4), hard, slabby to locally platy partings, highly calcareous, locally micaceous, local silty laminations, locally abundant layers of small (<3 mm) pelecypods, indeterminate bone fragments. Very argillaceous, glauconitic, oolitic (?) limestone bed between 2462.0-2464.0 ft. (750.4 and 751.0 m). Lower contact missing.

2482.0-2492.0 (756.5-759.5) (Rec. 2.4 m)
Mudstone: light olive grey (5Y6/1) to greenish grey (5GY6/1), hard, flaggy to platy partings, highly calcareous, micaceous, minor pyrite, trace of fish scales, trace of glauconite. Local laminations of micaceous silt. Occasional slickensides over lower 4 ft. (1.2 m). Lower contact missing.

2492.0-2496.0 (759.5-760.7) (Rec. 0.6 m)
Sandstone: light olive grey (5Y6/1) to light greenish grey (5GY8/1), hard, very fine to fine grain clear quartz, subangular to subrounded, poorly sorted, calcareous, silty, moderately to highly argillaceous, minor mica, minor pyrite. Numerous broken-up pieces of an interbed of argillaceous limestone with abundant rounded chert up to coarse grain size and floating very fine to fine grain clear quartz. Occasional piece of rubble with angular fragments of dolomite and chert grains in sandstone matrix. Lower contact missing.

Upper Watrous

2496.0-2507.0 (760.8-764.1) (Rec. 0.6 m)
Dolomite and Anhydrite: this interval consists of interbedded yellowish grey (5Y8/1), cryptocrystalline dolomite and light bluish grey (5B7/1) translucent anhydrite. Poor recovery. Lower contact missing.

Stratigraphic and Lithologic Relationships, Interlake Formation (Silurian), Southern Saskatchewan

by F.M. Haidl

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A study of the Interlake Formation (Silurian) in Saskatchewan was initiated in the fall of 1986. The main objectives of this study are 1) to refine the stratigraphy and 2) to investigate facies distribution and diagenesis with particular emphasis on porosity distribution. This report proposes a revised stratigraphic nomenclature for the Interlake and discusses briefly the lithologies and porosity development within it.

The Interlake Formation comprises a sequence of shallow-water carbonates and minor evaporites deposited in the Williston Basin during the Early to Middle Silurian (Johnson and Lescinsky, 1986; Carlson and Eastwood, 1962). These strata overlie Ordovician carbonates of the Bighorn Group with apparent conformity and are unconformably overlain by the argillaceous dolomites of the Middle Devonian Ashern Formation.

The Interlake Formation attains a maximum thickness of approximately 335 m in the central portion of the Williston Basin in North Dakota (LoBue, 1982). In Saskatchewan, it thins from 217 m in 10-28-1-10W2 in the southeastern area of the province to a zero edge in the west and north. This distribution of strata reflects both depositional thinning away from the centre of the basin and removal by erosion of a significant volume of rock some time between the Middle Silurian and Middle Devonian. The Interlake outcrops in Manitoba but is confined to the subsurface in the remainder of the Williston Basin. Records show that, to date, 521 wells have penetrated these strata in Saskatchewan; 86 of them are cored (71 diamond, 15 wireline). A complete Interlake section is cored (89 m) in only one well (PCS Mining Ste. Marthe 1-14-17-30W1). The remainder of the cores range from less than 3 m to 42 m in length.

To date no commercial accumulations of oil have been discovered in the Interlake Formation in Saskatchewan. However, in 1986, Interlake reservoirs in North Dakota produced 5.4×10^5 m^3 of oil (7.5% of the state's total production), and the data suggest that there may be reservoir potential in Saskatchewan. Zones with good to excellent porosity and permeability are present in cores and good porosity is indicated on geophysical logs in several wells. Further evidence of good porosity and permeability, at least in places, is provided by the utilization of the Interlake Formation for brine disposal at a number of potash mine sites. In addition, a number of oil shows have been recorded. The most significant show is from a drillstem test at 14-19-8-32W1 which recovered 27.4 m of oil, 30.5 m of oil-cut mud, and 36.6 m of water from an interval near the top of the Interlake.

Stratigraphy

The Interlake Group was originally defined by Baillie (1951) in the Manitoba outcrop belt as consisting of the basal Stonewall Formation overlain, in ascending order, by Units B, C, D and E. He deferred assigning formation or member names to these units until they could be established in the subsurface. Stearn (1956) removed the Stonewall Formation from the Interlake Group based on the interpretation that the Stonewall is Ordovician in age, whereas the Interlake is Silurian. He also subdivided the Interlake into the Fisher Branch, Inwood, Moose Lake, Atikameg, East Arm, and Cedar Lake Formations (in ascending order).

Porter and Fuller (1959) and Andrichuk (1959) extended the Interlake Group into the subsurface in the Williston Basin. Porter and Fuller (1959) separated the Stonewall Formation from the Interlake Group and subdivided the group into Upper, Middle, and Lower Beds based on "non-sequential" marker beds which contain terrigenous material defined by a high gamma-ray response on geophysical logs. The marker beds are interpreted as "para-time units" and a number of them can be correlated virtually basin-wide. The subdivisions thus defined are time-stratigraphic units and do not represent lithostratigraphic units (Porter and Fuller, 1959).

Further work in Manitoba by King (1964) traced the marker beds from the subsurface to the outcrop belt and defined a new set of formal lithostratigraphic units bounded by marker beds. In southern Saskatchewan, a somewhat similar stratigraphic breakdown was utilized by E.R. Jamieson in the late sixties. Her nomenclature has not been formally proposed but is outlined in a summary of well data and core descriptions (Jamieson, 1979) and in Broughton (1981).

Preliminary examination by the author of available data in Saskatchewan supports the conclusion reached by several other workers: in the subsurface, the Interlake cannot readily be subdivided into formal lithostratigraphic units (e.g., Porter and Fuller, 1959; Gibbs, 1972). A general lack of lithologic diversity, together with a paucity of core (particularly in the lower part of the sequence), preclude the definition of formations

which are "identified by lithic characteristics and stratigraphic position... and are traceable in the subsurface" (North American Commission on Stratigraphic Nomenclature, 1983, p. 841). The lithologic similarity between the Interlake and the underlying Stonewall Formation further complicates the definition of formal lithostratigraphic units (Kendall, 1976). Ideally, stratigraphic units within the Bighorn and Interlake Groups should be redefined so as to meet the criteria set out by the Stratigraphic Code (Kendall, 1976). However, it is unlikely that such a revision would be widely accepted, since it would necessitate extensive changes in existing data bases. Therefore, in this study, the present boundary between the Interlake and Stonewall (defined by gamma-ray log response) is retained but, because the Interlake Group cannot be subdivided into formations, it is reduced to formation rank. In North Dakota and Montana, the Interlake is already defined as a formation, although Gibbs (1972) incorporates a portion of the Stonewall interval within it (Gibbs, 1972; Carlson and Eastwood, 1962).

The stratigraphic nomenclature proposed for use in Saskatchewan is summarized in Fig. 1. The Interlake Formation is recognized as the formal lithostratigraphic unit which overlies the Stonewall Formation (Ordovician) and underlies the Ashern Formation (Middle Devonian). The informal subdivision of the lower portion of the Interlake (Lower Interlake Unit) is based on marker beds (defined by gamma-ray log response) which can be correlated with varying degrees of confidence across most of the basin. The names adopted are those utilized by Jamieson (1979), with unit boundaries similar to those of King (1964). In the upper portion of the Interlake (Upper Interlake Unit), beds defined by high gamma-ray values do not appear to correlate readily over significant distances; therefore, the division between the Middle and Upper Interlake made by Porter and Fuller (1959) on the basis of gamma-ray response is not adopted here. However, although not clearly defined by geophysical logs, distinctive lithologic characteristics observed in cores and samples of the uppermost Interlake in southeastern Saskatchewan allow delineation of the Taylorton Member as a lithostratigraphic unit. This is equivalent to the Taylorton Unit identified in core descriptions by Jamieson (1979). The subunit between the top of the Lower Interlake and the base of the Taylorton Member is named the Cedar Lake following the terminology of Jamieson (1979).

Lower Interlake Unit

The Lower Interlake Unit is composed of yellowish-grey fine-grained dolomites which have been subdivided into the Strathclair (lowermost), Fife Lake and Guernsey (uppermost) subunits by the "u" and "u_2" marker beds (Fig. 1). The base of the unit is defined by the top of the uppermost

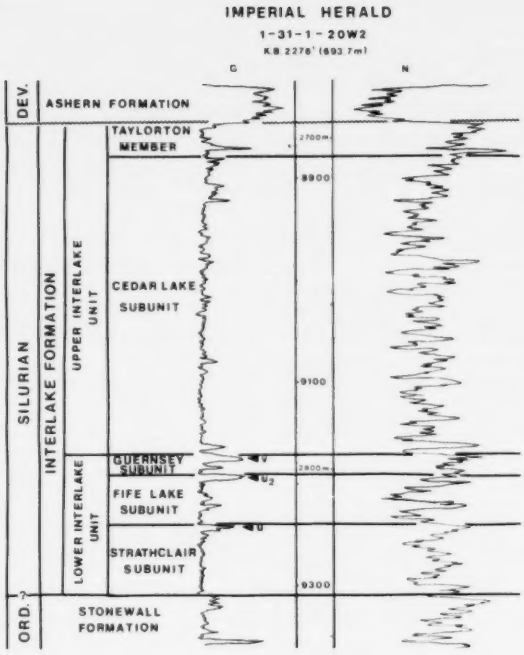
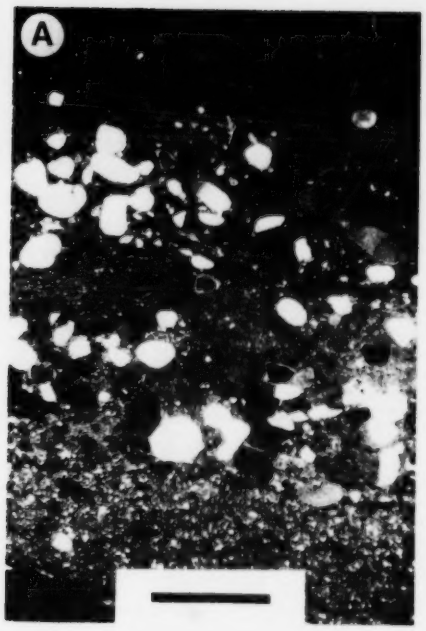


Figure 1 - Typical geophysical well log of the Interlake Formation showing the stratigraphic nomenclature proposed for Saskatchewan; location of "u", "u_2", and "v" marker beds is indicated.

Stonewall marker bed; the upper boundary is defined by the top of the "v" marker bed. The marker beds range in thickness from 1.0 to 2.5 m and are composed of argillaceous microdolomites which commonly contain laminations and/or scattered grains of very fine to coarse-grained quartz (Plate 1A). The mechanism(s) responsible for deposition of these beds is not clear. They may represent the final stages of transgressive-regressive cycles related to eustatic sea level changes (Johnson and Lescinsky, 1986). Based on this assumption, the top of each subunit is placed at the top of the respective marker bed (i.e., at the close of a depositional cycle).

Strathclair Subunit

The Strathclair subunit consists of dolomitized mudstones interbedded with dolomitized wackestones, packstones and grainstones which contain poorly preserved fossil fragments including corals, brachiopods, stromatoporoids, gastropods and ostracods (Plate 1B). The uppermost unit in the Strathclair is the "u" marker bed, which is characterized by microcrystalline dolomites with abundant argillaceous, silty and arenaceous laminae (Plate 1A). Molds of skeletal halite crystals were observed in this bed at 1830.5 m in core from



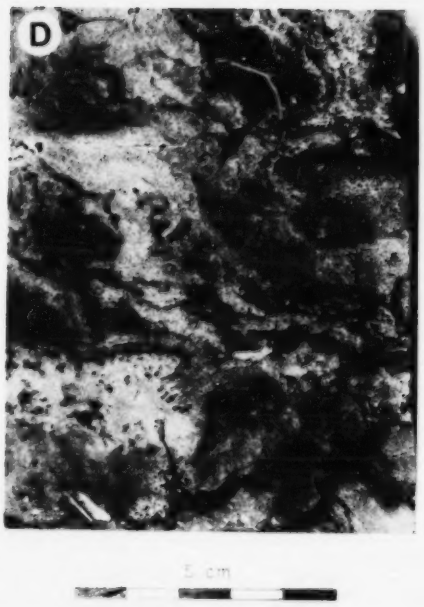
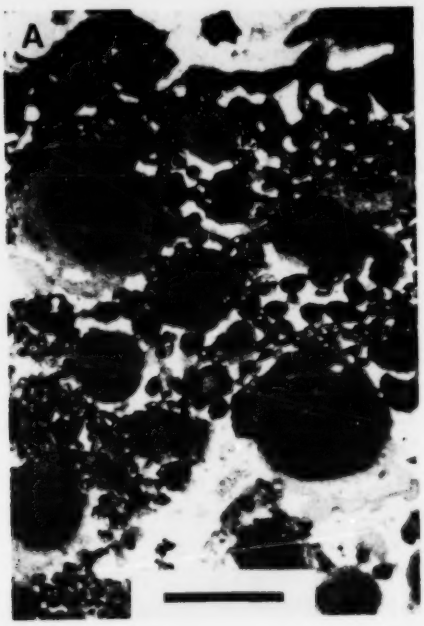


Plate 1 - A) Thin section photomicrograph of an irregular lamination of quartz grains in the "u" marker bed at the top of the Strathclair subunit 16-10-4-4W3, 2423.6 m; several grains display corrosion rims (arrows), a product of chemical interaction between carbonate and quartz; scale bar is 1.0 mm. B) Dolomitized skeletal wackestone containing corals, brachiopods and gastropods, Strathclair subunit, 1-14-17-30W1, 1186.1 m; poor intraparticle and biomoldic porosity. C) Small linked columnar stromatolites overlain by skeletal wackestone with good biomoldic porosity, Fife Lake subunit, 1-14-17-30W1, 1158.5 m; stromatolites with very similar morphology are present in outcrop at the Inwood Quarry, Manitoba. D) Coral-stromatoporoid boundstone composed predominantly of favositid corals and tabular encrusting stromatoporoids, Cedar Lake subunit, 12-21-2-29W3, 2455.2 m; good intraparticle and biomoldic porosity.



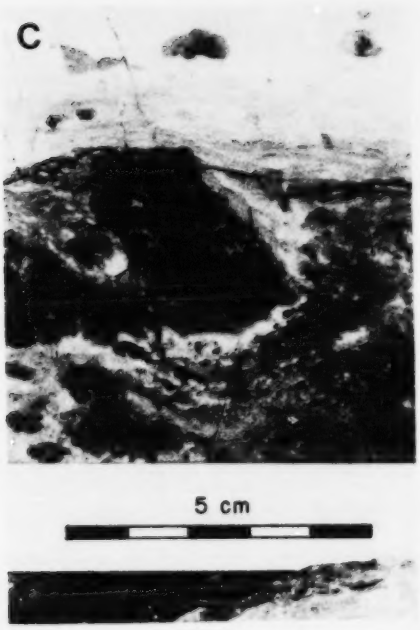


Plate 2 – A) Thin section photomicrograph of a grainstone composed of peloids and coated grains, Taylorton Member, 9-34-3-4W2, 2390.9 m; irregular laminations on coated grains and the presence of microstalactitic cement in adjacent fenestral pores suggest formation in a vadose environment; scale bar is 1.0 mm. B) Thin section photomicrograph of filaments of cyanobacteria (blue-green algae) Ortonella(?), Taylorton Member, 9-34-3-4W2, 2367.5 m; scale bar is 0.1 mm. C) Cyclic sequence in the Taylorton Member, 9-34-3-4W2, 2388.4 m; contact between brecciated mudstone (with abundant white dolomite cement) at top of one cycle and lithoclastic wackestone at base of overlying cycle. D) Thin section photomicrograph of inclusion-rich microstalactitic cement (dolomitized) which infills a sub-horizontal crack in a peloidal-algal wackestone/packstone, Taylorton Member, 9-34-3-4W2, 2367.5 m; scale bar is 1.0 mm; crossed nicols.

15-28-12-2W2. The marker bed is also partially iron stained in this core and in others from 12-21-2-29W2 and 16-10-4-4W3.

Zones with good to excellent porosity are developed in the Strathclair in several wells. A porosity of 14 percent was measured in a sample of skeletal wackestone from 1-14-17-30W1 (1181.7 m); the permeability is 21 millidarcies. Intercrystalline, intraparticle, biomoldic, vuggy and fracture porosity types were all observed in core.

Fife Lake Subunit

The Fife Lake subunit is composed predominantly of dolomitized laminated mudstones. Interbeds of wackestones and packstones containing corals, crinoids, stromatoporoids, brachiopods and gastropods are common, particularly in the upper and lower portions of this interval. Thin beds of oolites and skeletal grainstones are also present. An algal origin is interpreted for some of the laminated sequences. Small columnar stromatolites occur in a core from 1-14-17-30W1 (Plate 1C). The top of the "u_2" marker bed defines the top of the Fife Lake. Additional beds with high readings on gamma-ray logs are present in this subunit in some wells in the central portion of the province (e.g., 13-34-33-23W2).

Zones with good porosity are developed in the Fife Lake in a number of wells. Fair to good interparticle and biomoldic porosity was observed in a few cored intervals. Fracture porosity is well developed in 1-14-17-30W1.

Guernsey Subunit

The Guernsey subunit is dominated by dolomitized mudstones which are commonly laminated (possibly algal). The argillaceous microdolomites of the "v" marker bed represent the uppermost strata in the Guernsey. Low porosity is prevalent throughout this interval except where fracture porosity is present.

Upper Interlake Unit

Over most of the study area, the Upper Interlake Unit is composed entirely of the Cedar Lake subunit, a sequence of yellowish-grey to yellowish-brown dolomites similar to those in the Lower Interlake. In southeastern Saskatchewan, where the thickest intervals of Interlake strata are preserved below the unconformity, the Cedar Lake is overlain by the Taylorton Member, a heterogeneous unit which includes intraclast and lithoclast breccias, fenestral fabrics and abundant dolomite cements.

Cedar Lake Subunit

The Cedar Lake subunit is dominated by dolomitized mudstone (commonly laminated), with interbeds of dolomitized skeletal-peloidal wackestones and packstones. Fossils (usually poorly preserved) include brachiopods, gastropods, crinoids, corals, stromatoporoids and algae. Coral-stromatoporoid boundstones up to 4.5 m thick are present in a few cores (Plate 1D).

Zones with fair to good biomoldic, intraparticle, vuggy and interparticle porosity are developed primarily in packstone and boundstone intervals. In 1-14-7-30W1, five full-diameter samples have an average porosity of 11 percent and an average permeability of 489 millidarcies.

Argillaceous beds with high gamma-ray log readings similar to those which characterize the Lower Interlake occur in the Cedar Lake but they have a more limited lateral extent. A thin (<1 m) bed, 1.5 to 3.0 m above the "v" marker bed, appears to be the most laterally extensive of these (Fig. 1). It is lithologically similar to the "v" bed, and the close vertical proximity of the two commonly results in uncertainties in correlation (cf. Porter and Fuller, 1959, Fig. 7; Brindle, 1960, Fig. 2). Other beds with similar log responses are seen in core to be thin (<0.1 to 0.3 m) beds of shale. Some of these probably represent quiet water deposition of terrigenous material, but other intervals of red and green coloured shales may represent terra rosa deposits which have infiltrated fractures or developed in situ.

Taylorton Member

The Taylorton Member is composed of dolomites in which primary textures are commonly obliterated by brecciation and complex diagenesis. The member is characterized by brecciated textures, fenestral fabrics and multiple generations of dolomite cement in a variety of habits. Peloids, ooids, pisolites and laminated mudstones can be identified in both brecciated and unbrecciated sequences (Plate 2A). Algal fragments, ostracods and gastropods are the most commonly observed fossils (Plate 2B). Many different varieties of fenestral fabrics are present, including laminoid, irregular and tubular (Havard and Oldershaw, 1976; Read, 1973; Tebbutt et al., 1965). A number of cores include cyclic sequences which grade up from lithoclastic wackestone/packstone to mudstone; the upper portion of each sequence is commonly brecciated (Plate 2C).

Cementation is common in Taylorton strata. On a macroscopic scale, dolomite cements form "crusts" around intraclasts, and infill fenestral pores and horizontal and vertical cracks (Plate 2C). In thin section, observed fabrics of dolomite cements include microstalactitic and isopachous rims, and

subequant mosaics (Plate 2D). Anhydrite cement is also present; in most cases, it appears to be the latest generation of cement.

Zones with good porosity are not common in the Taylorton Member. In general, porosity appears to be associated with open fractures and with fenestrae which are only partially filled with cement. Analysis of 19 samples from 14-19-8-32W1 (the well in which 27.4 m of oil was recovered in a drillstem test) yielded an average porosity of 8.6 percent; maximum porosity is 11.8 percent. Average permeability is 6.7 millidarcies; maximum permeability is 44 millidarcies. However, the core displays abundant natural fractures which should significantly enhance effective permeability in the subsurface. In contrast, in 9-34-3-4W2, 45 samples were analyzed and only 8 recorded porosity values of 5 percent or greater; maximum porosity is 6.3 percent. Measured permeabilities exceeded 10 millidarcies in only 7 samples and were less than 1.0 millidarcy in 20 samples.

Beds characterized by high readings on gamma-ray logs are present in the Taylorton Member but, as in the Cedar Lake subunit, they cannot be easily correlated from well to well. Some of the thicker beds (2.5 m) are composed of large dolomite clasts in a green and red shale matrix; these may represent solution collapse breccias (e.g., 2578.3 m, 8-23-3-24W2).

Ashern/Interlake Contact

In core, the contact between the Ashern and Interlake is defined by a sharp erosional contact at which the reddish-brown or greenish-grey argillaceous dolomites of the Ashern overlie the grey, commonly pink-stained dolomites of the Interlake. Angular clasts of Interlake are commonly incorporated in the lower few metres of the Ashern. Beds of nodular to massive anhydrites may also occur in the lowermost Ashern. The uppermost Interlake commonly contains fractures filled with red and green shales.

Correlation of cores and geophysical logs indicates that this contact is usually clearly defined on logs by a sharp increase in values on gamma, neutron and sonic logs (Fig. 1). However, the lowermost Ashern is in places no more argillaceous than the uppermost Interlake, making it difficult to pick the contact on gamma logs. In addition, the presence of anhydrite in the Ashern results in less of a contrast between the Ashern and Interlake on neutron and sonic logs. These factors may result in the top of the Interlake being picked too high on logs; it is estimated that this error is generally less than 2 m and seldom more than 5 m.

Discussion

More detailed sedimentologic, petrographic and geophysical log correlation studies are required to improve the interpretation of the depositional and diagenetic history of Interlake strata in Saskatchewan. However, some generalizations can be made based on preliminary observations and data provided by other workers. Lower Interlake and Cedar Lake strata were deposited in shallow marine environments ranging from subtidal to supratidal with salinities ranging from stenohaline to hypersaline (Johnson and Lescinsky, 1986; Kent, 1984; Jamieson, 1968; Roehl, 1967). Reef development is indicated by coral-stromatoporoid boundstone intervals in the Cedar Lake subunit in a number of cores (Jamieson, 1968, 1979; Kent, 1984). This entire sequence probably represents a number of transgressive-regressive cycles related to sea level changes (Johnson and Lescinsky, 1986). Diagenesis in the Lower Interlake Unit and the Cedar Lake subunit includes cementation, recrystallization, dissolution of fossils and cements, and pervasive dolomitization.

Interpretation of the depositional and diagenetic history of the Taylorton Member is difficult. Primary textures are commonly destroyed by early diagenesis and brecciation; pervasive dolomitization has further obscured the entire sequence. Lithologic and petrographic evidence, including dessication cracks, microstalactitic cements, pisolites, common erosional surfaces, possible root casts, teepee structures and incipient soil breccias, indicate that Taylorton strata in Saskatchewan have undergone periodic subaerial exposure and vadose diagenesis. The restricted fauna (gastropods, ostracods and algae) suggest hypersaline to fresh water. E.R. Jamieson Magathan (pers. comm. 1987; Jamieson, 1973) interprets these strata as fluvial and lacustrine deposits which have been subjected to subaerial exposure. Alternatively, these deposits may represent restricted marine deposits with a complex diagenetic history including periodic subaerial exposure and vadose diagenesis (Roehl, 1967). Similar diagenetic features are reported in marine deposits by other authors (e.g., Assereto and Folk, 1980; Havard and Oldershaw, 1976; Read, 1973).

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Note on a Jura-Cretaceous Section in Central Southeastern Saskatchewan

by J.E. Christopher

Christopher, J.E. (1987): Note on a Jura-Cretaceous section in central southeastern Saskatchewan; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

Background

Transitional Jurassic-Cretaceous sandstones and shales, which have traditionally been included within the Cretaceous Mannville Group, are distributed across a 21,000 km^2 area of southeastern Saskatchewan, between the Third Meridian and the Manitoba border at latitude 52°N (Christopher, 1980, Fig. 3). They are encountered at depths below ground of 330 to 430 m and they range in thickness between 60 and 214 m.

These deposits came under scrutiny during the major petroleum exploration wave of the decade 1951-60, when most of the large oil fields of Saskatchewan were discovered (Halabura, 1987). Interest in the region was stimulated by the presence of numerous structural anomalies, since then attributed to salt-solution phenomena, but interest waned in the absence of any oil discovery.

A study of the Lower Cretaceous in southeastern Saskatchewan was published by Price (1963, 1964) who introduced the formation names Pense and Cantuar (younger to older) for the strata below the Albian Joli Fou shale and above the Jurassic and older formations forming the basal unconformity.

As implemented by Price (op. cit.), the regional Cantuar Formation also included Jura-Cretaceous strata, subsequently recognized as the Success Formation (Christopher, 1974). The latter formation is not present in the type Cantuar section. All three formations are separated one from the other by erosional unconformities. These are here labelled respectively the sub-Pense, sub-Dina and sub-Success (Fig. 1).

The sub-Success (Oxfordian-Kimmeridgian) and the sub-Dina (Neocomian) unconformities reflect underlying erosional topographies with relief up to 100 m, and in places the younger intersects the older. Gentler in relief but more profound areally, the sub-Pense unconformity represents a marine planation which has transected underlying formations as old as the upper Paleozoic (Christopher, 1980, 1984). Recognition of these unconformities is essential to an understanding of regional late Jurassic - early Cretaceous geology and petroleum reservoir relationships in the oilfields of southwestern Saskatchewan.

In the cross-section of Fig. 1 all those formations are present, but the Cantuar and Success Formations vary drastically in thickness by virtue of the unconformable relationships. It is also apparent that structural contact has participated in the shaping of topography.

[1]Consultant, Regina, Saskatchewan.

Sohio Western Prairie Insinger No. 1 (Lsd. 9, Sec. 16, Twp. 29, Rge. 7W2; K.B. 1705 ft. (519.7 m).

In the absence of cored wells through the Jura-Cretaceous in the study area, recognition of distinguishing lithologies is dependent on geophysical log correlation from outside the region and rock cuttings from wells within. Stratigraphic thickness of the sub-Joli Fou clastics varies areally from 61 m to 213 m. In that most of the wells are located on structural anomalies, all sections are apt to be 'anomalous'. The Sohio Western Prairie Insinger No. 1 well (Fig. 1), selected as a reference well for this area, may be extreme in this regard. However, the log expression is good, sample recovery is better than most and the stratigraphic section is representative. Typically, sample representation is biased toward cemented and indurated rocks, lignites and hard mineral species such as siderite and pyrite. Soft clays tend to disappear in the drilling mud and the washing process while shales, unless sufficiently conspicuous, are camouflaged by cavings from the Colorado Group.

The sub-Joli Fou clastics of Price (1963, Fig. 12) in the Insinger well lie between 1305 ft. (398 m) and 2000 ft. (610 m), i.e., stratigraphically between the Albian Joli Fou and Upper Devonian Torquay Formations. Price divides them into the Pense and Cantuar Formations at 1343 ft. (409.6 m).

In this paper the Pense-Cantuar contact is lowered to the disconformity at 1372 ft. (418.5 m), and the base of the Cantuar is placed at 1600 ft. (488 m), i.e., at the base of the Dina member of the Mannville Formation by correlation with the Lloydminster district of western Saskatchewan. The remainder of Price's Cantuar section, i.e., the strata between 488 m and 610 m, is here taken as the stratigraphic equivalent or homologue of the Jura-Cretaceous 'Success' Formation.

Success Formation

Three depositional sequences, each terminating in coal beds, are apparent in the Insinger No. 1 well. These are designated units A, B and C (oldest to youngest) in the lithological description below.

Overall, the formation is dominated by quartzose sandstones ranging in grade size from very fine to grits and conglomerates, with subordinate amounts of grain-aggregates and cements of brown siderite and pyrite, as well as fragments and grains of chert and chalcedony, black shale and red-brown dolomite. Calcareous cement has a minor presence in Unit C, but white siliceous kaolinitic matrix is pervasive.

Unit A comprises coarse sands and grits interbedded with a smaller proportion of poorly sorted fine to medium sands. Overall grade size decreases upward. Pyrite-cemented sandstones are conspicuous beneath the coaly and carbonaceous uppermost beds and above black shales basal to the unit. Lithic grains are conspicuous in the lower two-thirds of the unit and reflect basal Mississippian and Upper Devonian rock sources.

White chert fragments, both porcelaneous and chalcedonic, preempt the lower two-thirds of Unit B to a thickness of 27 m. As also observed by Price (1963), chert fragments are all broken cleanly by the drill bit, as if derived from slabs larger than the 9-inch diameter of the well bore. Scarce remains of crinoid ossicles suggest an ultimate Mississippian limestone source. The upper portion of Unit B features the more typical fine to medium kaolin-indurated sphaerosideritic quartzose sandstone with subordinate beds of black coaly shales. It is capped by lignite beds over an interval of some 6 m.

Unit C samples indicate a rather uniform suite of white kaolin and silica-cemented fine quartzose sands with some calcareous and marly interbeds, as well as brown siderite- and brassy pyrite-cemented beds. A coal bed with an overlying red oxidized shale marks the unconformity with the Cantuar Formation and caps the unit.

Lithology of the 'Success' homologue was derived from drill cuttings and is detailed in the following log. Depths are expressed in feet, with the metric equivalent in parentheses.

Unit C:

1610 (491.0): Shale, hematite-red.

1620 (494.1): Coal, black, shiny.

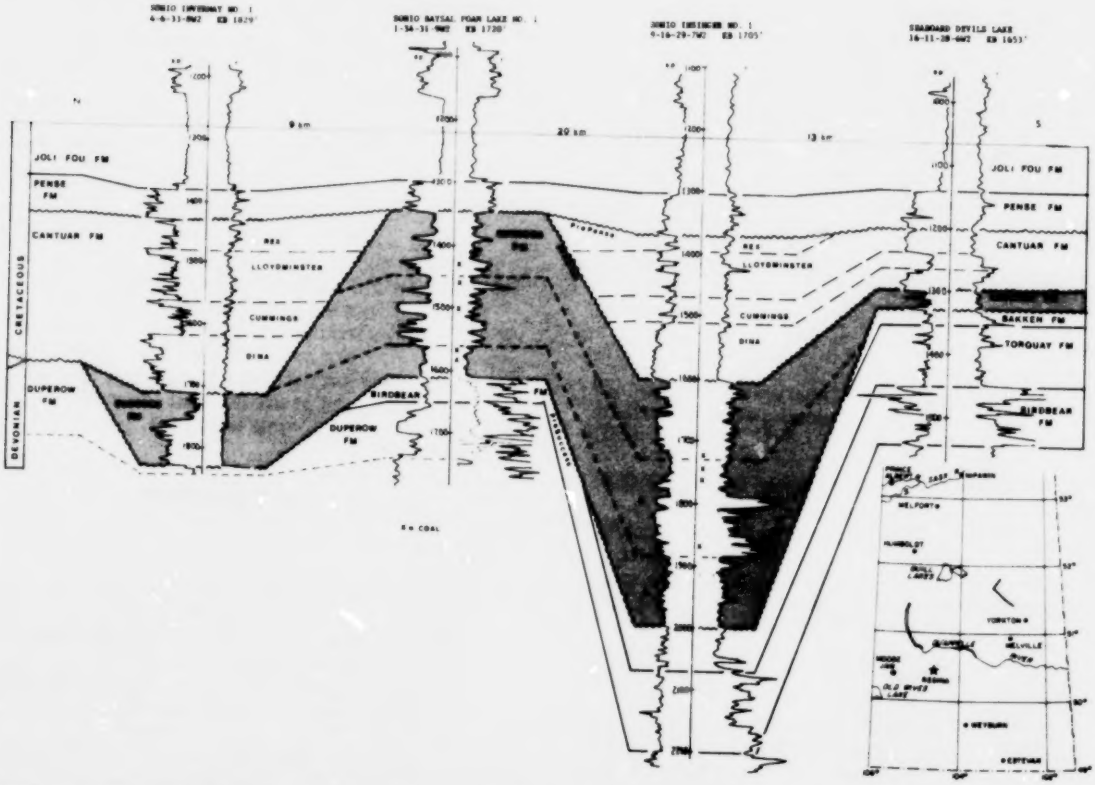

Figure 1 - North-northwest to south-southeast cross-section showing interrelationship of the Pense, Cantuar and 'Success' Formations at the Insinger No. 1 well and vicinity, southeastern Saskatchewan.

1630 (497.2): Sandstone, quartzose, medium and coarse grained, abundant white and pink feldspar, iron-stained quartz biotite aggregates.

1640 (500.2): Sandstone, quartzose, fine, well sorted, white, siliceous, kaolin-indurated, microvuggy, noncalcareous.

1650 (503.3): Mudstone, white, siliceous, kaolinitic, brittle, earthy.

1660 (506.3): Ditto, but finely speckled with brown siderite. Also sphaerosiderite, dark brown, coarse sand size; some grains are magnetic.

1670 (509.4): Sandstone, quartzose, fine grained, white, well sorted; grain-contact calcite cemented.

1680 (512.4): Ditto.

1700 (518.5): Marlstone, grey-white, well indurated, hackly fracture.

1710 (521.6): Sandstone, quartzose, fine grained, well sorted, pyrite cemented; also white fine-grained quartzose sandstone speckled with siderite; and coarse-grained siderite-cemented spheroidal fine quartz-sand aggregates.

1720 (524.6): Ditto.

Unit B:

1730 (527.7): Lignite - mostly durain with minor vitrain and carbonaceous shale.

1740 (530.7): Ditto.

1750 (533.8): Sandstone, quartzose, fine to medium grained, partially pyrite cemented

1760 (536.8): Sandstone, quartzose, fine to medium grained, white, kaolin-indurated, noncalcareous; also coarse-grained sphaerosideritic aggregates of fine quartzose sand.

1770 (539.9): Coal and carbonaceous shale; also medium grey micaceous shale

1780 (542.9): Sand, coarse; quartz, white and pink feldspar, black chert, quartz-biotite clusters, and green lithic fragments; some quartz shows crystal faces (cavings?)

1790 (546.0): Ditto.

Chert beds: 1800 - 1840 (549.0 - 562.2)

a) Chert fragments, porcelaneous, milky white, aphanitic; trace of silicified crinoidal columnals, compound pisolites, silica-drusy; sharply angular; some pyrite-infilled fractures; also

b) Chert fragments, white, earthy, porous; also as rinds to cores of (a).

c) Black shale.

1840 - 1890 (562.2 - 576.5)

a) Chert fragments, chalcedonic, translucent, light grey, abundant platy shards; also about 30 percent of porcelaneous cherts and black bituminous shale. Hydrous iron-oxide (rust) fracture and interstitial filling at 1880 ft. (573.4 m).

Unit A:

1900 (579.5): Coal, black carbonaceous shale and medium grey shale. Also sandstone, quartzose, fine-grained, pyrite cemented.

1910 (582.6): Sandstone, quartzose, fine to medium grained, pyrite-cemented, black and gold flecked; also sandstone, quartzose, coarse grained and grit; unfractured grains are rounded.

1920 (585.6): Sandstone, quartzose, fine to medium grained, poorly sorted; abundant black chert; larger grains are rounded, well cemented in microcrystalline quartz; some grains are sutured to pyrite-cemented sandstone.

Grit beds: 1930 - 1990 (588.7 - 607.0)
Grit, quartzose, subrounded; clear and frosted quartz grains grading in size to medium; abundant black chert, red and buff dolomitic mudstone and argillaceous dolomite disappearing below 1930 ft. (588.7 m). Interbeds of pyrite-cemented fine quartzose sandstones, iron rusted in part and at base; abundant white chert.

2000 (610.0): Shale, black, waxy, hard. Contact on tan, microcrystalline dolomite of the Torquay Formation.

Cantuar Formation

At the Insinger No. 1 well, the Cantuar lithology above the Dina Member is dominated by fine-grained sandstones, siltstones and mudstones variably cemented with calcium carbonate. Some sandstone beds are indurated with white kaolinite. Matrix colours range from white through green, grey and dark grey especially in the argillaceous beds. Brown sphaerosiderites, made up of siderite-cemented aggregates of fine quartz sand, are well represented at intervals of 12 to 18 m. Likewise, depositional sequences show a tendency to coarsen upward from calcareous mudstones to very fine quartzose sandstones. Accessory minerals include green biotite, muscovite, finely disseminated pyrite and white kaolinized feldspars.

The Dina Member features a characteristic suite of fine, well-sorted, quartzose sandstone, interbedded and laminated with very fine quartzose sand and silt. As elsewhere, a depositional break in the member is indicated - here by presence of a coal bed at 1560 ft. (475.8 m).

Sample quality through the Cantuar Formation is poorer than that of the underlying Success. Also, because the lithology is apparently thinly interbedded in a range limited to the smaller grade sizes, stratigraphic definition is poor. Thus no attempt has been made to identify in the samples the geophysical log units marking the Cummings, Lloydminster and Rex Members.

Rex Member

1380 (420.9): Sandstone, quartzose, fine grained, argillaceous matrix. Sample is dominated by sand bound up in coarse-grained sphaerosiderites; brown with some white kaolin. Grade size decreases to fine in sample 1390 ft. (424.0 m).

1390 (424.0): Siltstone, dark green-grey, argillaceous matrix, abundant muscovite and pyrite.

1410 (430.0): Siltstone, dark green-grey, argillaceous matrix, abundant muscovite and pyrite. Also shale, dark green-grey, scattered to abundant very fine pyrite.

Lloydminster Member

1420 (433.1): Sandstone, quartzose, very fine, well sorted, about 10 percent light brown siderite; light grey and brown speckled; well cemented with calcite; scattered green biotite, carbonized plant fragments and muscovite.

1440 (439.2): a) Sandstone, quartzose, very fine, well sorted, about 10 percent light brown siderite; light grey and brown speckled; well cemented with calcite; scattered green biotite, carbonized plant fragments and muscovite.

b) Siltstone, quartzose and argillaceous, well cemented with calcite; light grey, abundant carbonaceous specks.

c) Mudstone, medium green-grey; subordinate coarse quartzose silt, silica cemented.

1450 (442.3): a) Siltstone, quartzose, subordinate very fine quartzose sand, abundant muscovite and speckles of siderite; light green-grey, well cemented with calcite.

b) Mudstone, sideritic, dense, rusty brown; scattered coarse-grained sphaerosiderite and spheroidal siderite-cemented aggregates of fine quartzose sand.

1460 (445.3): a) Siltstone, quartzose, siderite cemented, dense, rust-brown; also siderite cemented mudstone.

b) Sandstone, quartzose, very fine grained, well sorted, calcite-cemented, white; speckled with scattered grey chert, brown siderite and white kaolinized feldspar.

c) Claystone, white, kaolinitic (mixed with drilling mud).

1470 (448.4): Ditto, a, b, and c.

Cummings Member

1480 (451.4): Ditto a, b, and c.

1500 (457.5): a) Siltstone, quartzose, siderite cemented, dense, rust-brown; also siderite cemented mudstone.

b) Sandstone, quartzose, very fine grained, calcite-cemented; siderite speckled.

1510 (460.6): a) Sandstone, quartzose, very fine grained, calcite-cemented; siderite speckled. Also brown sideritic ironstone.

Dina Member

1530 (466.7): a) Sandstone, quartzose, fine grained, abundant brown siderite; well cemented with calcite, light grey speckled with brown.

b) Sandstone, quartzose, fine to medium grained, abundant carbonaceous grains, muscovite and brown biotite; calcite cemented; white speckled with black. Some grains are pyrite cemented. Sample includes free, coarse-grained, rounded quartz and feldspar.

1540 (469.7): Sandstone, quartzose, fine grained, well sorted, white; calcite cemented, abundant pyrite crystals and siderite-coated quartz grains.

1550 (472.8): Sandstone, quartzose, very fine to silty, speckled with argillaceous and carbonaceous specks, well cemented with calcite, medium grey.

1560 (475.8): a) Marlstone, subordinate quartzose silt, dense, light grey.

b) Coal, brittle, high luster.

1570 (478.9) to 1600 (488.0): Inconclusive.

Conclusions

Mapping to date indicates the "Success" Formation to represent a depositional body discretely different from that of the Cantuar Formation. Its coarser fabric, more variable facies, and greater tendency to fine upward from coarse clastics, along with its more immature sediments, are characteristics identifiable in well cuttings, and serve to separate it from the Cantuar Formation. The latter in the area is definitely finer grained; the sands are more regular in size range, i.e., better sorted, more rounded and therefore more mature. Also noted is a tendency of the bedding groups to coarsen upward.

Finally, the top of the Success Formation is marked by an oxidation surface, noticeable in the well cuttings, not only at Insinger No. 1 but also at the adjacent Sohio Baysel Foam Lake No. 1 well in Fig. 1.

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Aspects of the Regional Geological Framework of Low-Permeability Shallow Gas Reservoirs in Upper Cretaceous Strata (Colorado and Montana Groups), Southwestern Saskatchewan

by C.F. Gilboy

Gilboy, C.F. (1987): Aspects of the regional geological framework of low-permeability shallow gas reservoirs in Upper Cretaceous strata, southwestern Saskatchewan; in Summary of Investigations 1987, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 87-4.

The Upper Colorado Group of southwestern Saskatchewan comprises predominantly dark grey marine shales, in part calcareous, which contain northeastward-thinning bands of fine-grained sandstone and siltstone up to several metres in thickness, as well as rare bentonite layers. The basal member, the Second White-Speckled Shale (upper Cenomanian and lower Turonian) is separated from the stratigraphically highest member, the First White-Speckled Shale (upper Coniacian and lower part of the Santonian), by an unnamed unit (upper Turonian and lower Coniacian) of noncalcareous shales.

Shaly fine-grained sandstones and siltstones of the Milk River Formation (upper Santonian and lower Campanian) overlie Upper Colorado strata, forming the basal stratigraphic unit of the Montana Group.

In southwestern Saskatchewan, these Upper Cretaceous rocks are economically important because they contain some 46.4×10^9 m^3 of nonassociated gas, more than half of the province's initial established reserves (Saskatchewan Energy and Mines, 1986). The three main gas pools in this part of Saskatchewan, namely Hatton, Bigstick and Liebenthal, lie at the southeastern limits of the very large Southeast Alberta Gas System which, in Alberta, contains initial established reserves of nonassociated gas in Upper Colorado - lowermost Montana Group rocks of 286×10^9 m^3 (Energy Resources Conservation Board, 1985). These pools are currently being rapidly developed, and extensive exploration is in progress to try to maintain high reserves.

The Upper Cretaceous rocks belonging to the same stratigraphic interval in northern Montana host productive gas pools such as East Keith (some 180 km southwest of Hatton), Tiger Ridge, Bowes and Bull Hook (approximately 200 km south of Hatton with reserves estimated at more than 21×10^9 m^3 (Maher, 1969)), and Bowdoin (approximately 250 km southeast of the Hatton Pool with cumulative production of 0.19×10^9m^3 to the end of 1978, [Nyedegger et al, 1979]). Farther south and east, gas pools such as Hardin, Liscom Creek, Pumpkin Creek, Cedar Creek, West Short Pine Hills and Cady Creek (southeastern Montana and northwestern South Dakota) are further evidence of the widespread occurrence of Upper Cretaceous shallow gas reservoirs in the northern Great Plains of North America. Rice and Shurr (1980) and Rice and Claypool (1981) have suggested that the northern Great Plains might contain about 3.25×10^{12} m^3 of shallow gas, with recovery volumes dependent upon well-completion technology and revenue-to-cost ratio of the gas.

The author's preliminary study area in southwest Saskatchewan covers Townships 1 to 23 and Ranges 21W3 to 30W3, inclusive. A grid of northeast-southwest and northwest-southeast stratigraphic cross-sections will be constructed to trace, as far as possible, lithostratigraphic units between the base of the Lower Colorado Group and the top of the Milk River Formation currently recognized in southeastern Alberta and northern Montana into southwestern Saskatchewan. Revisions to Saskatchewan's Upper Colorado stratigraphic nomenclature are likely to be recommended. Also, updated isopach, structure and net-pay maps will be prepared. These, supplemented by petrologic examination of cored intervals and by investigation of geothermal gradient and hydrodynamic regime patterns, will be used to reappraise the geometry, sedimentology and economic potential of Upper Colorado - lower Montana Group strata. Subsequently, the study-area will be expanded eastwards and northwards.

Previous Work

Pioneer geological studies of Cretaceous strata of the northern Great Plains region were largely carried out by the Geological Survey of Canada (e.g., Dawson, 1875, 1882; Dowling, 1917; Dowling et al., 1919; Dyer, 1926a; Williams and Dyer, 1930; McLearn et al., 1935) and the United States Geological Survey (e.g., Stanton and Hatcher, 1905; Bowen, 1914; Stebinger, 1914).

Geological publications about oil and gas accumulations in Alberta and adjoining areas began to appear in the 1920s and 1930s. They ranged in scope from description of individual fields in various stages of discovery and development (e.g., Clark, 1923; Hume, 1924; Perry, 1928) to regional assessments (Dyer, 1926b; Ross, 1926; Hume, 1933). These and subsequent similar works enabled important contributions towards present understanding of Cretaceous depositional environments, facies distribution, chronology and paleogeography of the North American Western Interior Seaway to be presented by, amongst others, Williams and Burk (1964), Kauffman (1969),

Obradovich and Cobban (1975), Stelck (1975), Williams and Stelck (1975) and Caldwell (1982). These, in turn, provided useful regional settings for detailed geological research of Upper Cretaceous strata in the northern Great Plains, such as has been published by Suffield Block Study Committee (1972), Last, Kloepfer Ltd. (1973), Suffield Evaluation Committee (1974), Meijer Drees (1973, 1975), Myhr and Meijer Drees (1976), Meijer Drees and Myhr (1981), Male and Pacholko (1982) and Warren (1985), mainly from southeastern Alberta; by Christopher et al. (1971), Simpson (1975, 1979a, 1979b, 1980, 1981a, 1981b, 1981c, 1982, 1983, 1984a, 1984b), Simpson and Katham (1980), Simpson and Singh (1980) and Singh (1982), mainly from southwestern Saskatchewan; and by Rice (1976a, 1977, 1980, 1981), Shurr (1979, 1984a, 1984b), Nydegger et al. (1979), Rice and Claypool (1981), Rice and Shurr (1980, 1983), Gautier (1981), Gautier and Rice (1982), Gautier et al. (1983), Shurr and Reiskind (1984), and Shurr and Rice (1986, 1987), mainly from Montana and adjacent states.

Regional Stratigraphy and Related Nomenclature Problems

The stratigraphic nomenclature currently in common usage for correlating Upper Cretaceous strata in southeastern Alberta, southwestern Saskatchewan, and north- and east-central Montana is shown in Fig. 1.

Units that make up the Upper Colorado Group in southwestern Saskatchewan and southeastern Alberta are, for the most part, informally defined (First White-Speckled Shale, "unnamed noncalcareous shale", Second White-Speckled Shale) and appear to lack type localities. North and Caldwell (1975, p. 306) noted the unsatisfactory nomenclature applied to the Cretaceous rocks of Saskatchewan, and pointed out that sequences of this age are closely similar to those in Montana and in North and South Dakota, so that many stratigraphic names originating and used in these states "could be applied with advantage north of the International Boundary". The author concurs with their statements.

Rice (1981) has published a 511 km long, 12-well subsurface cross-section of Cretaceous (mostly Upper Cretaceous) strata from close to the northwest end of the Southeast Alberta Gas System to the southeast end of the Bowdoin Gas Field, and has shown that formation-top picks are clearly traceable over this distance. Simpson (1981a) used selected U.S. stratigraphic terminology in core descriptions of Upper Colorado strata and on a cross-section in extreme southwestern Saskatchewan.

North and Caldwell (1975, Fig. 2) showed two hiatuses in the Colorado Group, one above and the other below an unnamed shale which rests upon the Fish-Scale Sandstone. Simpson (1982b) recognized no stratigraphic break within the Big River Formation, which he described as lying both above (the unnamed shale of North and Caldwell) and below the "Fish-Scale Marker". However, he noted the presence of a disconformity above the Big River Formation, most pronounced in central Saskatchewan where the uppermost beds appear to have been removed by erosion and where, in an eastward direction, successively younger strata rest upon Big River shales and mudstone. North and Caldwell recognized another hiatus between the First White-Speckled Shale and the Milk River - Lea Park Formations.

Meijer Drees and Myhr (1981) proposed that the predominantly subtidal and intertidal nearshore deposits which form highly productive natural gas reservoir rock in the Southeastern Alberta Gas System (Milk River Gas Pool) be termed the Alderson Member of the Lea Park Formation. They selected the type section in the ARCO Alderson well (Lsd. 10-4-15-10W4) between depths 253.5 and 338.3 m. Other authors (e.g., Rice, 1981) have used the term "Milk River Equivalent" for these rocks. In Saskatchewan, Simpson and Singh (1980) adopted unqualified use of the term "Milk River Formation", largely because this name is so deeply entrenched in the oil and gas industry and related literature.

Both the stratigraphy and the nomenclature of Upper Colorado Group rocks will be further reviewed in course of this study.

Lithology and Sedimentology of Reservoir Rocks

Second White-Speckled Shale/Greenhorn Formation

Simpson (1981a) examined and described ten cored intervals collected from this unit in the study area; since this work was done, core has been recovered from a further 19 wells. Simpson assigned rocks of the Second White-Speckled Shale, which is up to 61 m thick in southern Saskatchewan, to the Greenhorn Lime with a maximum core thickness of 3.5 m, and/or to the stratigraphically lower Phillips Sandstone with a maximum cored thickness of 20.6 m.

The Phillips Sandstone is made up of interbedded, fine-grained, pale olive-grey to grey sandstone and siltstone, along with generally subordinate dark grey mudstone which is bituminous in places. Lithologic layers mostly range in thickness from a few millimetres to several centimetres. They are commonly horizontally laminated, but some thicker siliciclastic layers are cross-laminated. Sandstone layers are quartzose and micaceous, and in many places have sharp bases and indistinct siltstone and/or mudstone tops. Horizontal to subhorizontal sand-filled burrows are locally abundant - sufficiently so in places to destroy primary layering across thicknesses up to 0.6 m. Some siltstone layers contain mud-filled Chondrites. Pale grey bioclastic limestone and chalk are sporadically

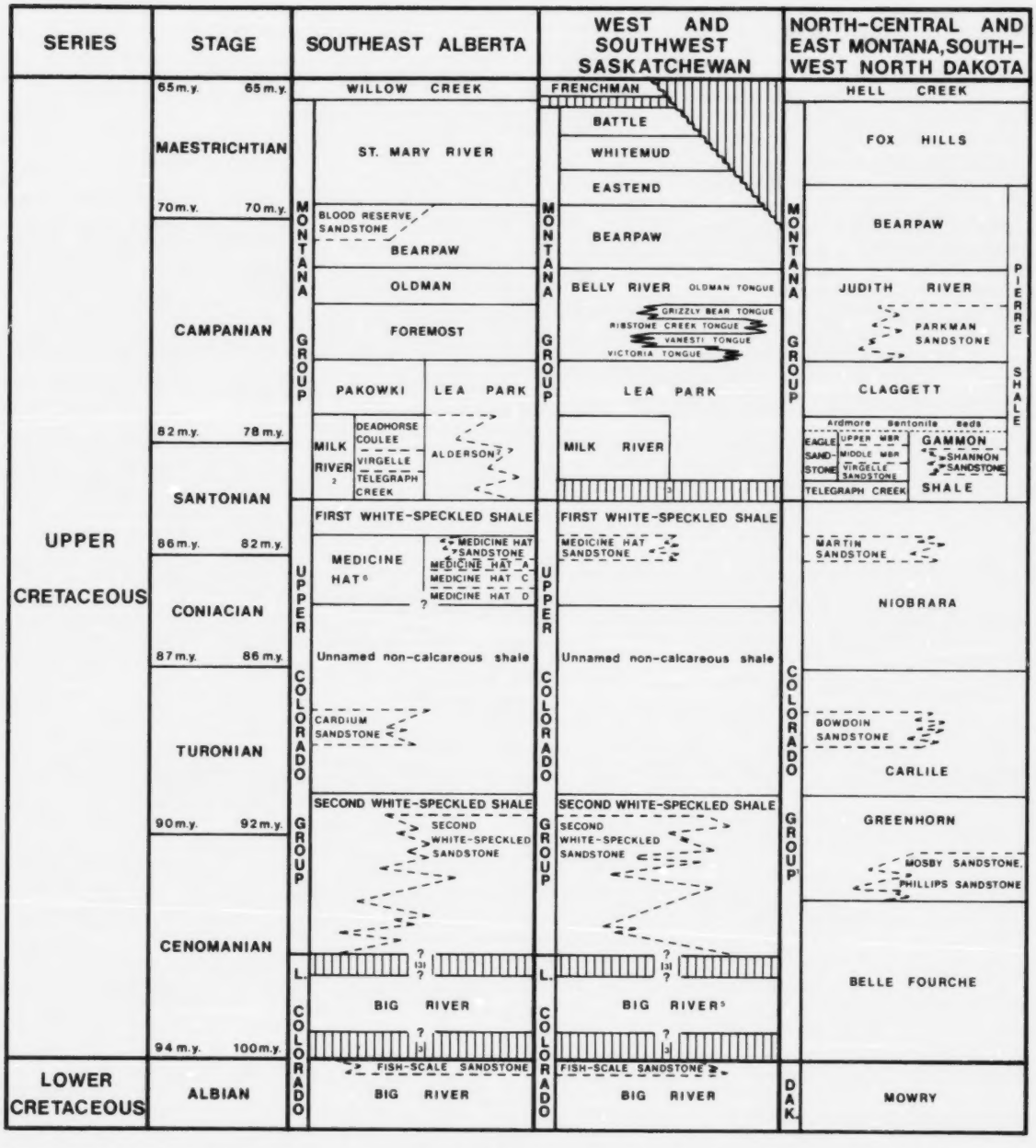

Figure 1 - Correlation chart of Upper Cretaceous rocks of the northern Great Plains (adapted from Bluemle et al., 1981[1]; Meijer Drees and Myhr, 1981[2]; North and Caldwell, 1975[3]; Rice, 1976b[4]; Simpson, 1982[5] and Warren, 1985[6]). Ages down the left side of the "stage" column are from Obradovich and Cobban (1975), those down the right side are from Van Hinte (1976).

distributed as layers 1 mm to 5 cm thick, especially in the uppermost 3 m where scarce calcite concretionary layers up to 20 cm thick are also found. Pelecypod, coccolith and fish debris are sporadically present and locally abundant, as are plant-fragment occurrences in some sandstone beds.

Within the Phillips Sandstone, upward-coarsening sequences defined by upward decrease in the

proportion of intercalated mudstone are common, and an overall northward decrease in grain size has been noted (Simpson, 1982a), along with attenuation of the lowermost sand of the Phillips Sandstone. A transition from thick (in the southwest) to thin (in the northeast) Phillips Sandstone development trends northwesterly from about Twp. 3 Rge. 13W3 to Twp. 12 Rge. 24W3 and possibly farther (Simpson and Katham, 1980). In Saskatchewan's Bigstick Gas Pool, which is situated at a depth of about 692 m, the average thickness of pay sand totals 3.73 m and the porosity is 20 percent. Westwards, in Alberta, gas reservoirs at this stratigraphic level are mostly 600 to 630 m deep, 0.75 to 2 m thick and have a porosity of almost 22 percent.

The Greenhorn Lime, up to about 6.5 m thick in southern Saskatchewan, is predominantly dark grey, coccolithic, silty mudstone which is bituminous in millimetre-thick layers and contains pale grey limestone and chalk layers ranging in thickness from less than 1 mm to about 2 cm. Horizontal lamination is well developed, cross-lamination less so. Inoceramus and fish skeletal debris are common. Pyrite concentrations, where present, are usually elongate in the plane of bedding in carbonate layers. Bioturbation is rare.

A bentonite layer 0.3 to 0.7 m thick at the base of the Greenhorn Lime appears to be ubiquitous in the study area. It is horizontally laminated, biotite-rich and medium grey to pale bluish grey.

In the Bowdoin Dome area of north-central Montana, the Phillips Sandstone consists of three coarsening-upward cycles, individually up to 23 m thick, and identifiable on gamma-ray, density and resistivity logs (Nydegger et al., 1979). Cycles are shaly at the base and finely sandy at the top. Commercial production is from the tops of the upper two cycles where sandstones have estimated average porosities of 15 to 17 percent and permeability values of 2 to 3 md. The Greenhorn Lime in this region is dominantly a carbonate, the reservoir rock being finely crystalline limestone containing shell fragments and discontinuous laminae of organic-rich shale which are barriers to vertical permeability. The unit is brittle, and fractures readily in response to both natural and induced forces. Its porosity is 6 to 13 percent, and permeability ranges from less than 0.1 to 6 md. The base of the Greenhorn Lime here is a highly radioactive impure bentonite zone up to 12 m thick. It forms an impermeable barrier between reservoirs in the Phillips Sandstone and the Greenhorn Lime, and acts as a seal for gas entrapment. Nydegger et al. (1979) point out that, although the bentonite is composed of smectite and so is highly susceptible to swelling, production in adjacent reservoirs should not be affected because, at the shallow depths involved, fracturing in them should move horizontally.

Rice and Shurr (1980) considered the Phillips Sandstone to be an "offshore bar" shelf sandstone of a type that generally forms narrow elongate bodies and that Walker (1984), from a study of ridges developed in modern shelf and shallow marine sands, showed as having ranges in height, length and width of 3 to 12 m, 3.7 to 18.5 km, and 0.9 to 2.8 km, respectively. Referring to paleogeographic maps published by Williams and Burk (1964), Rice and Shurr further considered that the Dunvegan delta, located in northwestern Alberta and adjacent British Columbia, was the source for these clastics, even though Stelck (1975) pointed out that this delta complex seems to have been restricted to an area northwest of the Peace River Arch (Fig. 2). Rice (1984) showed that the Phillips Sandstone in the Bowdoin Dome area and the stratigraphically equivalent Mosby Sandstone of the Central Montana Uplift were deposited in higher energy environments than contemporaneous sediments in intervening areas where relatively low-energy conditions prevailed.

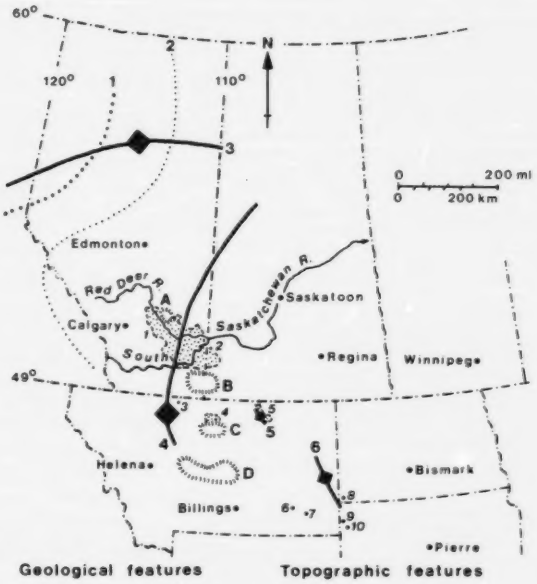

Figure 2 - Map showing locations of major geological structures and topographic features quoted in the text.

Medicine Hat Sandstone/Martin Sandstone

In southwestern Saskatchewan, the Medicine Hat Sandstone occurs about 25 to 30 m below the top of the First White-Speckled Shale, at a depth of approximately 500 m in the Hatton area and 520 m in the Burstall area. Rocks of this unit in the study area have been described by Simpson (1981a) from 11 cores from Twps. 12 to 18, Rges. 28 to 30W3. Since publication of Simpson's report, five cores containing Medicine Hat Sandstone have been taken from within the study area, the most southeasterly being from Twp. 5 Rge. 26W3 in a region where the Medicine Hat Sandstone is barely distinguishable on geophysical logs. Where completely represented by core sections, the Medicine Hat Sandstone ranges in thickness from 7.3 to 9.6 m; geophysical logs show it attains a maximum thickness of about 13.7 m.

This rock unit is made up of fine-grained, medium grey to pale olive-grey speckled sandstone interbanded with medium dark grey speckled muddy siltstone and dark grey mudstone. Bands occur as lenses and continuous layers up to a few centimetres thick, with numerous but discontinuous mudstone partings a few millimetres thick. Sandstone layers are quartzose, micaceous and cross-laminated or horizontally laminated. They incorporate moderately abundant pelecypod (especially Inoceramus) and fish skeletal debris.

The top of the Medicine Hat Sandstone is generally strongly indurated across a thickness of 0.05 to 0.5 m, providing an effective cap rock to underlying gas-bearing strata. Indurated horizons of similar thickness also occur at lower levels in the unit, having formed where calcite cemented and partially or completely plugged siliciclastic layers of relatively high original porosity and permeability below bentonitic permeability barriers. Cone-in-cone structures commonly occupy the top 2 cm of indurated zones, which have polygonal patterns ornamenting their uppermost surfaces (Kendall and Simpson, 1974).

Simpson (1981b) describes an informal three-fold subdivision of the Medicine Hat Sandstone with a 1.5 to 3.5 m thick zone of predominant, upward-coarsening, fine-grained sandstone (the main reservoir rock) sandwiched between zones of muddy siltstone and subordinate fine-grained sandstone (0.5 to 4.0 m thick above the main sandstone, 3 to 4 m thick below). Rare granules and small pebbles of nodular siderite are present in all three subdivisions.

Thin, laminated bentonites (mostly about 2 cm thick) occur at several levels in the Medicine Hat Sandstone, especially the uppermost 0.3 m, as well as in the overlying First White-Speckled Shale.

The lower contact between the Medicine Hat Sandstone and the First White-Speckled Shale is gradational, while the upper contact (which is below 25 to 30 m of First White-Speckled Shale) is generally sharp. East and north of the Hatton area, the Medicine Hat Sandstone is increasingly fine-grained and shaly. In the Hatton area, the average net thickness of pay zones in the Medicine Hat Sandstone is about 3 m and, in the Burstall area, about 2.8 m (Saskatchewan Energy and Mines, 1986); respective porosities are 21 and 16 percent, and the permeability ranges from 0.1 to more than 250 md (Simpson, 1981b).

In the Medicine Hat area of southeastern Alberta, this unit forms the reservoir for the Medicine Hat A Gas Pool, contains a higher proportion of relatively well-washed fine-grained sandstone, and has a net-pay thickness of 3.88 m and an average porosity of 17 percent. Elsewhere in this gas pool in Alberta, pay thickness ranges between 0.48 m (Johnson Field) and 3.45 m (Cassils Field). Warren (1985) provided a type log showing gamma, neutron and density porosity, and resistivity curves for the Milk River, Medicine Hat and Second White Specks Formations. He showed the Medicine Hat Formation to be a 60 m thick unit. Earlier ERCB reference logs (attachments to Decision 77-9 respecting Application No. 770202; attachment to examiners' report on Application No. 8981) show the Medicine Hat Formation to comprise three upward-coarsening sequences which are, from bottom to top, reservoirs for designated gas pools Medicine Hat D (about 40 m thick), Medicine Hat C (some 20 m thick) and Medicine Hat A (about 12 m thick).

The Medicine Hat C Gas Pool (0.36×10^6 hectares) is smaller in area than the Medicine Hat A Pool (1.73×10^6 hectares), has an average pay thickness in the range of 0.53 m (Atlee Buffalo Field) to 1.17 m (Cassils Field) and only rarely exceeding one metre, and has an average porosity of 14 percent. The Medicine Hat D Gas Pool is smaller (0.27×10^6 hectares), has thinner pay (0.4 m in Bindloss Field to 1.12 m in Suffield but mostly less than 0.75 m) and an average porosity of 14 percent (Energy Resources Conservation Board, 1985).

Last, Kloepfer Ltd. (1973) constructed net-pay isopach maps for the Medicine Hat Sandstone using contours of 0 m (0 ft.), 3.0 m (10 ft.), 6.1 m (20 ft.) and 9.1 m (30 ft.). The producing unit was found to be delta-shaped, its apex (in Twp. 10 Rge. 8W4) pointing to the southwest, and made up of northwest-trending sand ridges averaging about 30 km in length, 3 km in width and attaining about 10 m in height. The authors concluded that the Medicine Hat Sandstone was deposited as a delta that was reshaped by wave-action and longshore currents. The 130 km long delta front is oriented northwest-southeast and is situated about 110 km from the apex, which lies close to the crest of the Sweetgrass Arch so that the delta sands fan away on both the northwestern and southeastern flanks of the rch. Sandstone thicknesses exceeding 6.1 m are concentrated along a northeast-trending zone which, though affected by sand-ridge development, extends from close to the delta apex to the delta

front. This zone of maximum sand thickness may represent deposits of the main distributary channel.

In a more recent study (Martin Petroleum Consulting Ltd., 1985), the Medicine Hat Sandstone was interpreted to be a nearshore marine deposit with its source area to the south and southwest. Alternatively, it may be a shelf sandstone similar in origin to the Phillips Sandstone (Rice and Shurr, 1980).

In the northern Great Plains region of the U.S., the Niobrara Formation consists predominantly of chalk and chalky shale (Shurr, 1984b; Shurr and Rice, 1986), which are southerly counterparts of the First White-Speckled Shale that, in Saskatchewan, lies below, to the northeast of, and above, the Medicine Hat Sandstone. Sandy horizons appear to be rare except in north-central Montana, where the Martin Sandstone forms a 7.5 to 12 m thick unit in the Bowdoin Dome area (Rice, 1981). Although gas-bearing, the Martin Sandstone had not yielded commercial quantities of gas to 1979 (Nydegger et al., 1979). Shurr and Rice (1987) state that, in the Dakotas, chalk units in the Niobrara Formation are potential gas reservoirs that might contain in excess of 1700×10^9 m^3 of gas in place.

Milk River Formation/Alderson Member/Eagle Sandstone/Gammon Shale (and Shannon Sandstone)

The Milk River Formation is about 115 m thick in southwestern Saskatchewan, with the top of the unit approximately 350 m deep in the Hatton area. Simpson (1981a) published brief descriptions of two of the three Milk River core sections then available from wells drilled in the study area; the longer core represented only one-fifth of the complete Milk River section. Subsequent natural gas development in the area has resulted in the current availability of another thirteen core sections from this unit. As stated earlier, unqualified use of the name Milk River Formation has been retained in Saskatchewan because it is so deeply entrenched in petroleum literature (Simpson, 1980).

In southwestern Saskatchewan, Milk River rocks in core comprise weakly consolidated, medium dark grey to medium grey muddy siltstone and pale olive-grey fine-grained silty sandstone. One or other of these two lithologies is alternately dominant in bands that grade into one another and are generally a few metres thick. Within the bands, the dominant rock type is mixed with subordinate amounts of the other main type. Relatively clean, coarser grained, better sorted salt-and-pepper sandstone makes up 10 to 15 percent of most Milk River core in the form of irregularly shaped, discontinuous, subhorizontal lenses and stringers which are up to about 5 mm thick and several centimetres across. Very rare conglomeratic bands, ranging in thickness from a single pebble to about 15 cm, being poorly sorted and containing matrix-supported angular to subangular clasts of chert and fine-grained felsite, are also present, as are pale green, finely laminated bentonite layers a few centimetres thick. Siderite and rare chert nodules 2 to 8 cm thick and up to more than 8 cm in maximum diameter occur at intervals a few metres apart.

Milk River rocks are made up mostly of sand-, silt- and clay-sized particles. Sand- and silt-sized particles are predominantly angular to subrounded quartz grains 0.05 to 0.15 mm (rarely up to 1.5 mm) in diameter. Clay-sized particles, by analogy with the Gammon Shale clay suite in southwestern North Dakota described by Gautier et al. (1983), comprise mixed-layer illite/smectite, discrete illite and mica, kaolinite and chlorite (see also Longstaffe, 1984). Biotite and white mica are ubiquitous and randomly distributed as subhorizontal flakes about 0.4 to 1.0 mm across, but make up less than 1 percent of either siltstone or sandstone. Dark-coloured equidimensional sand- and silt-sized particles have not, for the most part, been compositionally identified, but many are lignitic. Pyrite (and possibly some chalcopyrite) is commonly present as disseminated euhedra approximately 0.1 mm across, subhedral crystalline aggregates partially infilling shelly debris, or rare framboids (less than 0.05 mm diameter).

Primary lamination is only rarely preserved, most Milk River rocks in cored intervals appearing to have been thoroughly bioturbated. Recognizable subhorizontal burrows are moderately abundant. Most are mud-filled, flattened, 1 to 2 mm in diameter, slightly sinuous and rarely bifurcated; many of these have an iridescent dark blue-gold colouration, possibly due to lining or partial infilling by bornite or related sulphides. Some burrows are sand-filled.

Pelecypod, gastropod and Baculites debris are common, generally as shell fragments or Inoceramus prisms. However, complete Inoceramus valves up to about 6 cm long are preserved in places, as are open or closed articulated valves of unidentified pelecypods and complete gastropod (also unidentified) shells 1 to 5 mm long. Baculites shells are thin and delicate, and generally retain a beautiful mother-of-pearl iridescence. They attain lengths in excess of 8 cm and widths of 1.5 cm, and most have been completely flattened. Sutures have not been described to date. Chitinous fish remains have been seen, but are extremely rare.

Permeability of the Milk River Formation is mostly less than 0.23 md, and porosity values range from 13.6 percent to 17.8 percent (Simpson and Singh, 1980; Singh, 1982). Pay thickness ranges from close to 2 m (Liebenthal) through to 2.6 m (Burstall) to 6.8 m (Hatton) (Saskatchewan Energy and Mines, 1986).

In southeastern Alberta, the stratigraphic equivalent of that province's type Milk River Formation (as developed farther to the south and

southwest) and of southwestern Saskatchewan's Milk River Formation, the Alderson Member of the Lea Park Formation, has been defined and described by Meijer Drees and Myhr (1981). These authors considered that the rocks of the Alderson Member had initially been deposited in nearshore subtidal to subtidal and intertidal environments, and were thus transitional between a sandy nearshore, foreshore, shore and backshore facies (the Eagle and Milk River Formations) and a marine, offshore shale facies (the Lea Park Formation). The member is about 85 m thick and consists of thinly and lenticularly interbedded, bioturbated silty shale and laminated, in places bioturbated, very fine grained sandstone. The two lithologies form a sedimentological unit which resembles the "parallel laminated to burrowed sets" found in Recent sublittoral sediments. Thin, laminated and thin lenticular sandstone beds scattered through the lower part of the Alderson Member are the most porous and permeable rock types. Discontinuous zones of partly silicified siderite nodules, pebbly bands and bentonitic shale beds are also present. At the top of the member is a thin widespread sideritic claystone bed containing round black chert pebbles. It is overlain by Claggett (or Pakowki) Shale.

Previous to the study by Meijer Drees and Myhr (1981), Last, Kloepfer Ltd. (1973) had suggested that the sediments which now make up the reservoir rocks of the Milk River Formation were originally chenier deposits, composed of coarse silts, wood, shells and minor sand. They were laid down as northwest-trending, 3 to 6 m high, approximately 1500 m long beaches developed by longshore current and wave activity along the seaward margin of a delta during periods of marine stillstand and consequent slow deposition. Such periods alternated with those of rapid deposition of clays and finer grained silts as mudflats offshore from the delta.

Sea-level fluctuations produced vertical stacking of at least six reworked chenier-ridge complexes. A major episode of marine offlap, followed by onlap of the Pakowki (Lea Park) sea, gave the Milk River Formation reservoir rocks their present regional configuration (i.e., shaling out on all sides except the southwest). Last, Kloepfer Ltd. (1973) pointed out that here, northeast-trending channel sands were developed with a sequence of coals, carbonaceous sands and silts, the continental facies of the Milk River Formation. Bentonite beds, some of which are regionally correlatable, are numerous. In southwestern Saskatchewan, Singh (1982) used two such regionally recognizable markers to subdivide the Milk River Formation into Lower (poorly prospective for gas), Middle (containing the most prospective gas-bearing strata) and Upper (a few gas occurrences present) units.

The Milk River Formation, as recognized by Meijer Drees and Myhr (1981), is a northwestern continuation of Montana's Telegraph Creek and Eagle Formations and has been subdivided into three members named, from bottom to top, Telegraph Creek, Virgelle and Deadhorse Coulee. Because of this direct correlation, Milk River Formation geology in the type area (McCrory and Walker, 1986) is here inherently included with the geological summary of the Eagle Sandstone/ Gammon Shale (and Shannon Sandstone).

The 1.55×10^6 hectare Milk River Gas Pool in Alberta has an average depth of 355 m. Its pay thickness ranges from 1.88 m (Bow Island Field) to 10.32 m (Cassils Field), with most fields containing 3 to 6 m; and its average porosity is 15.4 percent (Energy Resources Conservation Board 1985).

In Montana, the Eagle Sandstone formed as a coastal blanket deposited in wave-dominated deltaic and interdeltaic environments along the western shoreline of the Western Interior Seaway (Rice and Shurr, 1983). In the east, it comprises elongated sand ridges of the inner shelf, up to 15 m thick and reworked by storm waves, and thin, discontinuous storm-generated beds that display parallel or ripple laminations and sharp bases or are extensively bioturbated and that are intercalated with shale. In the west, the Eagle Sandstone conformably overlies the Telegraph Creek Formation, which consists of offshore marine siltstones and shales interbedded with thin shelf sandstones. These increase in number and thickness upward, and the formation is transitional between calcareous shale of the underlying Niobrara Formation and interdeltaic coastal sandstone of the overlying Virgelle Sandstone Member (the 25 to 40 m thick basal unit of the Eagle Sandstone). The 20 to 50 m thick Middle Member of the Eagle Sandstone overlies the Virgelle Sandstone Member, and is made up of a lower unit of predominant mudstone which alternates with siltstone, sandstone and some coal beds, and an upper unit of fine- to medium-grained sheet-like sandstone. The lower unit probably represents coastal-plain deposits which formed behind the Virgelle strandline, whereas the upper unit was probably deposited in a deltaic environment. The lithologically variable 10 to 30 m thick Upper Member of the Eagle Sandstone rests disconformably upon the Middle Member. More northerly outcrops are made up of interbedded sandstone, siltstone and shale. More southerly outcrops consist of one or two upward-coarsening sequences which grade from interbedded sandstone to resistant sandstone ledges. In both areas, chert gravel containing a few shark teeth is scattered or concentrated into laminae or beds and appears to be a lag deposit.

The coastal sandstones and nonmarine rocks of the Eagle Sandstone grade eastwards into offshore marine siltstones and shales of the Gammon Shale, which is about 100 m thick at its western boundary in Central Montana, increasing to about 300 m at the North Dakota - Montana border (Gautier, 1981). Farther eastward, it thins and disappears. In the upper part of the Gammon Shale, upward-

coarsening sandstone sequences, the Shannon Sandstone Member, have been deposited near the edge of a broad shelf more than 320 km from the western shoreline of the Western Interior Seaway (Shurr, 1984). Genetic processes leading to the development of the Shannon Sandstone, a ridge field of complex linear sand ridges, are not presently clearly understood, but probably involve tectonic as well as sedimentation events (Shurr, 1984a). The top of the Gammon Shale is a strict time line at the base of the Ardmore Bentonite Beds, a widespread stratigraphic marker in the northern Great Plains (Gautier, 1981).

The Eagle Sandstone is a gas reservoir in the Tiger Ridge Field north of the Bearpaw Mountains, where most production is from the Middle and Upper Members. The sandstones are generally highly porous (20 to 30 percent) and permeable (100 to 300 md), though these properties are strongly controlled by diagenetic processes, especially those related to chemically enriched waters resulting from igneous activity (Gautier and Rice, 1982). The Gammon Shale contains gas in thin (less than 1 cm thick) discontinuous lenses and laminae of siltstone and very fine grained sandstone and, because of its immense volume and potential for biogenic gas generation, is considered by Gautier and Rice (1982) to hold the greatest potential for shallow gas production in the northern Great Plains. Gas is produced from the upper 80 to 100 m of the 300 m thick Gammon Shale in the Little Missouri Field, southwestern North Dakota. Porosity averages about 21 percent, and permeability less than 1 md.

Natural Gas: Its Origin, Accumulation and Development

A biogenic origin has been convincingly argued for natural gas in shallow Upper Cretaceous reservoirs in the northern Great Plains of the U.S. and Canada (Rice and Claypool, 1981). Not only is this gas composed almost entirely of methane (C_1/C_{1-5} ratio greater than 0.98), but it is isotopically light ($\delta^{13}C_1$ generally in the range -65 to -70 ppt). Moreover, the various requirements for the commencement and maintenance of biogenic methane production appear to have prevailed in the host rocks. These requirements include an anoxic, sulphate-deficient environment, suitable temperatures (0 to 75°C), space in which methanogenic micro-organisms can function (not a problem until muds have been buried to about 2000 m), and the presence of organic matter (in excess of about 0.5 percent organic carbon). Jones et al. (1986) concur with Rice and Claypool's (1981) findings.

Accumulation of biogenic gas requires that certain physicochemical and sedimentological conditions for concentration and entrapment be met. Rice and Claypool (1981) pointed out that, in nonmarine and brackish-water environments that are generally low in sulphate, methane production begins close to the surface, but most is lost by aerobic bacterial oxidation or escape to the atmosphere because of low hydrostatic pressures. In marine sediments, biogenic methane can be retained in solution in interstitial water because of higher hydrostatic pressure due to the overlying water column. This methane can be held until traps and seals are formed through sediment compaction (depths of burial greater than 500 m generally necessary) and other processes. Continued biogenic methane production in excess of solubility, or exsolution of gas due to hydrostatic pressure reduction (e.g., lowering of sea level, uplift and erosion, upward migration of gas-bearing waters to zones of lower hydrostatic pressure) leads to the formation of a free gas phase which, in the northern Great Plains area, was probably stratigraphically trapped in discontinuous, relatively impermeable silt and sand enveloped by organic-rich mud.

Porous and permeable reservoirs are often flushed with fresh water, and natural gas accumulates only in closed structural traps. In the northern Great Plains, numerous bentonite beds and carbonate-cemented layers also acted as excellent seals enabling gas accumulations to form. Rice and Claypool (1981) noted that most biogenic gas pools are at shallow depth and so have low reservoir pressure. In fact, many are underpressured in relation to prevailing hydrostatic pressure gradients, perhaps because of dilation of pore volume and decrease of reservoir temperature associated with uplift and erosion, thus helping to trap the gas. Closed structures such as the Bowdoin Dome and the Cedar Creek Anticline may have some effect upon the location of productive gas accumulations, but are not all-important (Gautier and Rice, 1982).

Hitchon (1984) studied geothermal gradients and hydrodynamic regimes in southeastern Alberta. He noted that recharge areas are the Cypress Hills, the surface-water divide between the South Saskatchewan and Red Deer Rivers, and the Hand Hills. Discharge areas are the major river valleys and Pakowki Lake. Furthermore, formation waters near the base of the Lower Cretaceous strata and near the base of the Upper Cretaceous strata have higher hydraulic heads than those near the top of the Lower Cretaceous. Northwards, this zone of lower hydraulic head moves up-section from the Bow Island Formation into the Second White-Speckled Sandstone. The Milk River Formation and Medicine Hat Sandstone have higher hydraulic heads than underlying or overlying rocks, so formation-water flow is upward from the Milk River Formation into the Pakowki Formation and downward from the Medicine Hat Sandstone into the Lower Cretaceous or the Second White-Speckled Sandstone. The southern side of the Southeast Alberta Gas System occurs where recharging waters from the Cypress Hills change flow direction from northwards to vertically downwards or southwards. The northern limit is similarly defined by changing flow directions of

recharge waters from the Hand Hills. Throughout most of the Southeast Alberta Gas System, the hydraulic gradient is low compared to that below the Cypress Hills and the Hand Hills. This hydrodynamic regime, Hitchon (1984) suggested, is clearly the major controlling influence upon the location of the Southeast Alberta Gas System, and is probably a much more important process than one such as exsolution of previously formed biogenic gas from interstitial water, especially as its pattern seems to have remained essentially unchanged since the early Eocene.

Drilling and completion techniques play a most important role in determining initial flow rates and cumulative gas production from wells tapping the extremely water-sensitive, shallow Upper Cretaceous reservoirs of the northern Great Plains (Nyedegger et al., 1979; Black et al., 1981; Evans, 1984).

In general, clear-water drilling fluids containing clay stabilizer (1 dm^3/m^3 3 percent KCl water) or low-fluid-loss, polymer-based muds have effectively reduced drilling times and borehole washouts in southeast Alberta and the Bowdoin Dome area. Clay accounts for 10 to 30 percent of reservoir rocks (Gautier et al., 1983; Evans, 1984), much of it highly expandable mixed-layer illite/smectite, leading to average permeability values that are often less than 0.1 md.

Hydraulic fracturing is needed to improve productivity, which is adversely affected by low permeability and by low reservoir pressure. Evans (1984) recommended two-stage fracturing of the Milk River Formation to increase the thickness of stimulated zones after finding that after-fracture initial flow rates in a sixteen-well Bantry project undertaken by PanCanadian Petroleum Ltd. increased by 91 percent (or appoximately 3600 m^3/day). Production testing continues on these wells to see whether this improved production level is sustained. Evans (1984) considered that three-stage fracturing might lead to further incremental improvements in productivity.

Evans (1984) also summarized improvements in fracture treatment of shallow gas reservoirs, tested in a fourteen-well Medicine Hat - Milk River project in the Cassils Field. Modifications included replacement of the previously used fracture fluid (a KCl-water-Xanthan Gum mixture) by a KCl-water-Hydroxypropyl Guar mixture, and adoption of 20,000 kg of 12/20 sand per fracture treatment instead of 20,000 to 60,000 kg of 10/20 sand (50 percent) and 8/12 sand (50 percent; this sand has the undesirable potential to generate fines when pumped at high rates and high sand concentrations). Pumping rates were the maximum available, and sand concentrations were increased to 1000 kg/m^3 as fast as possible (more than 50 percent of each treatment was pumped at this concentration). A high sand concentration is advantageous because fractures with thin layers of sand proppant tend to heal in these shallow shaly reservoirs. Also, the amount of fluid required to stimulate the reservoir was minimized and clean-up time was reduced (the aid of CO_2 was required because of low reservoir pressure; flow-back rates were controlled so that CO_2 was effectively used to recover the maximum amount of fracturing fluid). Results showed that Medicine Hat initial production rates using the modified fracture treatment improved by 18 percent and those in the Milk River by 130 percent (in combination with two-stage fracturing).

Other stimulation has been attempted, generally without marked economic success, using other fracturing fluids and foams including viscous cross-linked gels, polyemulsions, gelled alcohol/water mixtures, and nitrogen foam with or without alcohol or carbon dioxide (Nydegger et al., 1979; Black et al., 1981).

Cumulative production figures for wells tapping the three main gas-bearing stratigraphic units in southwestern Saskatchewan are shown in Table 1. They appear to compare closely with production from an average Bowdoin area well, estimated by Nydegger et al. (1979) to be 9 x10^6 m^3 over a ten-year period. The Little Missouri Field in southwestern North Dakota is of special interest with regard to future exploration targets as it produces entirely from silt-shale reservoir rocks in the uppermost 80 to 100 m of the 300 m thick Gammon Shale. Initial gas flow for one well in the field was reported to be 17,000 m^3/day, achieved by stimulating a 27 m thick zone from a depth of 376 m to 403 m. This zone was selected using data derived from a full suite of porosity logs and an interpretation method described by Nydegger et al. (1979) (Gautier and Rice, 1982). Table 2 shows, for comparative purposes, information about gas reserves in selected Upper Cretaceous strata in the Southeast Alberta Gas System and its eastward extension into Saskatchewan, including smaller gas accumulations in southeast Alberta which are trapped at the same stratigraphic levels but which are located to the south of the main Southeast Alberta Gas System.

Conclusion

Since the 1950s, Upper Cretaceous siliciclastic and argillaceous rocks of the northern Great Plains region of Canada and the U.S. have attracted increasingly close interest from natural gas explorationists because they host, and are sources for, very large accumulations of biogenic methane. Their stratigraphic nomenclature, as currently used in Saskatchewan and Alberta, requires considerable refinement. As formations recognized in Upper Cretaceous strata of north-central and northeast Montana are, for the most part, clearly recognizable on geophysical logs from wells in southwestern Saskatchewan, the applicable stratigraphic nomenclature could usefully be extended into this province.

Table 1 - Natural Gas Production Figures for Selected Wells in Southwestern Saskatchewan

Producing Unit	Well Location	Production Period (days)	Cumulative Gas Production ($\times 10^6$ m^3)	Remarks
Milk River Formation	8-13-16-30W3	4059	7.29	Average production of an older well
	6-5-15-27W3	391	3.33	Completed in upper Milk River
	6-5-15-27W3	392	3.15	Comingled lower Milk River and Medicine Hat production
Medicine Hat Sandstone	6-21-18-29W3	5970	9.47	Below average
	10-31-15-28W3	7020	15.09	Average
	6-5-13-27W3	5442	26.56	Above average
	6-3-14-29W3	6062	51.95	Above average
Second White-Speckled Shale	10-16-14-26W3	1176	27.17	Development started too recently for average production to be calculated
	10-17-14-26W3	1703	27.84	

Table 2 - Reservoir Data for Natural Gas Pools in Selected Upper Cretaceous Strata, Southeastern Alberta and Southwestern Saskatchewan (Energy Resources Conservation Board, 1985; Saskatchewan Energy and Mines, 1986).

Producing Area (name)	Producing Stratigraphic Unit	Mean depth of unit (m)	Mean thickness or thickness range of pay in unit (m)	Producing area (size in hectares x 10^8)	Average Porosity (percent)	Gas Saturation (percent)	Initial Reservoir Pressure (kPa)	Raw Gas in place ($10^6 m^3$)	Producible Raw Gas ($10^6 m^3$)
Southeast Alberta Gas System	Milk River	355.7	1.88 - 10.32	1.37	15.4	55	3,140	165,824	116,121
	Medicine Hat A	487.7	0.55 - 3.88	1.61	17.0	55	4,310	168,450	114,465
	Medicine Hat C	487.7	0.53 - 1.17	0.36	13.9	60	4,450	11,601	5,800
	Medicine Hat D	487.7	0.40 - 1.12	0.27	13.9	60	4,450	9,707	4,854
	Second White-Speckled Shale (A, B, and C)	630.0	0.62 - 4.63	0.60	21.6	60	5,690	59,830	44,769
Fields to south of Southeast Alberta Gas System	Milk River	194.7 to 487.6	0.80 - 4.94	0.005	17.0	60	2,220 - 4,280	374	260
	Medicine Hat	274.0 to 487.7	1.00 - 1.54	0.007	22.0	55	2,590 - 4,500	455	319
	Second White-Speckled Shale	524.3 to 1026.6	0.47 - 3.60	0.013	12.0 to 32.0	40 to 70	3,230 - 5,540	677	487
Southwest Saskatchewan	Milk River	335.0 to 460.0	2.03 - 6.80	0.19	16.0	55	3,450 - 3,630	42,546	26,273
	Medicine Hat Sandstone	477.0 to 520.0	2.80 - 3.26	0.12	16.0 to 21.0	50 to 80	4,310	16,205	12,318
	Second White-Speckled Shale	692.0	3.73	0.027	20.4	70	6,105	12,406	7,823
							TOTAL	448,075	333,489

The potential for substantially increasing known gas reserves in Upper Cretaceous low-permeability shallow reservoirs in southwestern Saskatchewan are excellent, especially southwest of an imaginary line running southeastwards from the Burstall Field on the Saskatchewan-Alberta border to the Bowdoin Field adjacent to the Canada - U.S. boundary. This area probably lay in the outer shelf region on the west side of the Western Interior Seaway for prolonged periods during the Late Cretaceous. High erosion rates in land areas west of the Seaway combined with a wide shallow-water shelf resulted in ideal conditions for widespread depositon of thin (3 cm) sandstone units by storm-related geostrophic currents. These units are locally numerous enough in zones from one to several metres thick and upwards of 200 hectares in area that, if they are saturated with 50 to 65 percent of natural gas (the general range in presently producing fields), they form reservoirs containing ten million cubic metres (or more) methane and start to be of commercial interest. Sand ridges are also characteristically present in many storm-dominated shelf environments, both modern and ancient, and form producing reservoirs in the Shannon Sandstone of southeastern Montana and northwestern South Dakota at a distance of more than 300 km from the Seaway's western shore. Similar sand-ridge reservoirs may be present in Upper Cretaceous strata of southwestern Saskatchewan. Economically viable concentrations of gas may be discovered in siltstone-shale sequences of the Milk River Formation and the Gammon Shale away from producing fields, probably where siltstone is volumetrically dominant over shale in sufficiently thick, widespread areas (as in the Little Missouri Field, southwestern North Dakota).

Natural gas traps in Upper Cretaceous low-permeability rocks of the northern Great Plains are strongly controlled by subtle variations in the abundance of clay-sized particles relative to that of larger particles, in clay mineralogy, and in the size and horizontal continuity of sandstone and siltstone lenses within their argillaceous envelopes. They are essentially stratigraphic traps, but their gas producibility is commonly much improved if suitable closed structures such as the Bowdoin Dome are formed as a result of tectonism, salt solution, or differential sediment compaction. Also, long-established hydrodynamic regimes have probably exerted great influence upon the current geographic and stratigraphic location of northern Great Plains shallow gas fields, and should be accorded due attention during exploration.

Continued refinement of geophysical logging and log-interpretation techniques is required in order to improve further the explorationists' ability to distinguish between productive and nonproductive zones in clay-rich siliciclastic-argillaceous sequences.

During the past few years, improvements in well-drilling and -completion methods in water-sensitive reservoir rocks have led to substantial increases in initial flow rates from northern Great Plains shallow gas wells. If these increases are sustained long enough for cumulative production to be enhanced, significant lateral expansion of producing gas fields into areas outside their current economically viable limits is likely to follow. Also, other gas accumulations, hitherto uneconomic, will attract renewed interest with respect to development.

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Abstracts of Recent Saskatchewan Energy and Mines Publications and Papers by Staff of the Saskatchewan Geological Survey

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Gracie, A.J., Gray, L.J. and Boissoneault, G. (1987): Index to La Ronge Core Collection (to September 1, 1986); Saskatchewan Energy and Mines, Data File 12, 162p (last edition published as Open File Report 85-3).

Guliov, P. (1987): Industrial minerals of southern Saskatchewan; Geological Association of Canada/ Mineralogical Association of Canada, Joint Annual Meeting, Field Trip Guidebook, Trip No. 5, 50p.

Harper, C.T. (1986): Geology of the Nevins - Forsyth Lakes area; Saskatchewan Energy and Mines, Open File Report 86-4, 57p.

The area lies within the Western Craton Domain in Saskatchewan, which comprises variably reworked Archean gneisses and early Aphebian supracrustal gneisses, granitoids and other intrusions. Within the area mapped, the generally southeast-striking Oldman - Bulyea Lakes Shear Zone divides the area diagonally into two lithologically and metamorphically distinctive regions.

The region south of the Oldman - Bulyea Lakes Shear Zone is characterized by granulite facies grade gneisses which become progressively retrometamorphosed to amphibolite facies towards the shear zone. The region is dominated by garnetiferous and/or hypersthene-bearing feldspathic gneisses with minor pyribolite/amphibolite, iron formation, early metamorphosed mafic dykes, white pegmatites and abundant unmetamorphosed lamprophyre dykes. In the vicinity of the shear zone, pink granite sills and dykes intrude the retrograded gneisses and lamprophyre dykes.

The region nortn of the Oldman - Bulyea Lakes Shear Zone is characterized by amphibolite facies grade gneisses which show only local evidence of having reached granulite facies conditions and having undergone regional retrometamorphism. The dominant rocks are migmatitic quartzofeldspathic gneisses containing varying proportions of biotite and hornblende, with minor amphibolite and rare pelitic gneiss. A zone of granite emplacement parallels the Oldman - Bulyea Lakes Shear Zone, and numerous smaller sheets and dykes of granite and pegmatite occur throughout this region.

The Oldman - Bulyea Lakes Shear Zone and its subsidiary splay faults are defined by mylonite and mylonitic and augen gneiss. The main shear zone affects an area up to 2 km wide and commonly features epidotized fractures, brecciated mylonite and, in places, red colouration of the affected gneisses. The splay faults are defined by narrow zones of mylonite, 1 to 3 m wide.

Outcrop patterns and small-scale structures in both regions indicate the presence of complex fold interference patterns. The earliest folds in both regions appear to be overturned southwesterly-dipping isoclines. These are refolded about generally upright northwest-striking axes and by later, more open, upright northeast-striking axes. The Oldman - Bulyea Lakes Shear Zone truncates these earlier structures and, in places, has caused regional-scale drag folding. The shear zone may represent a major thrust system and lesser thrust slices, whereby the higher grade gneisses of the southern region were brought into juxtaposition with the slightly lower grade gneisses of the northern region.

Noneconomic and subeconomic mineralization within the area is present mainly in the southern region and includes:

1) relatively thin bands of sulphide (pyrite-pyrrhotite) and oxide (hematite) facies iron formations;

2) minor concentrations of uraninite in pegmatitic and granitic rocks; uraninite, allanite and monazite are associated with very coarse masses of biotite in some white pegmatites;

3) yellow secondary uranium bloom associated with granitic segregations and uraniferous pegmatites;

4) uraninite or pitchblende occurring along the contact of mafic lamprophyre dykes and the adjacent country rocks;

5) rare earth element-bearing monazite concentrations of suspected detrital origin occurring in ilmenitic garnet±hypersthene feldspathic gneisses, particularly in the southwest part of the area; and

6) scattered occurrences of molybdenite in late pink granite and pegmatite.

Harper, C.T. (1987): The Archie Lake rare earth element (ilmenite-monazite) showing: an Archean(?) heavy mineral placer deposit, northwestern Saskatchewan; Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, Saskatoon, May 25-27, 1987, Program with Abstracts, v12, p52.

The Archie Lake ilmenite-monazite showing occurs in granulite facies gneisses exposed along the north shore of Lake Athabasca and lies within the Keewatin Zone, a broad region of reworked Archean basement with remnant pockets of Early Proterozoic supracrustal rocks. The showing was found as the result of an airborne radiometric survey carried out in 1968 by Trans Canada Resources Ltd. It occurs in an 8 to 10 m wide horizon of generally ilmenite-rich hypersthene-garnet-feldspar gneiss within a package of quartzofeldspathic, quartzitic, arkosic and pelitic gneisses. The mineralized zone, which averages 5 m wide and has been traced for 600 m, consists of 10 to 50 percent ilmenite with corresponding values for the millimetre-sized yellow monazite. This showing is the most significant rare earth element (REE) occurrence in Saskatchewan, with geochemical values ranging from 0.1 to 15.7 percent total REO (rare earth oxide), as well as containing 0.1 to 2.31 percent ThO_2, 0.002 to 0.014 percent U_3O_8, a trace of Au and up to 16 percent TiO_2. A partial analysis of the REE indicates the following decreasing order of abundance: Ce, La, Nd, Gd, Er, Dy, Eu, Yb, Lu, Tb. The stratabound character of the mineralization and the common occurrence of ilmenite and monazite in heavy mineral beach sands strongly suggests that the showing is of syngenetic origin, and as a consequence implies the existence of a basement-cover relationship in this area.

Kent, D.M. and Christopher, J.E. (1987): Paleozoic and Mesozoic stratigraphy of the northern Williston Basin region; Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, Field Trip Guidebook, Trip No. 3, 72p.

Lane, D.M. (1987): Subsurface carbon dioxide in Saskatchewan: sources and potential use in enhanced oil recovery; Saskatchewan Energy and Mines, Open File Report 87-2, 40p.

Carbon dioxide (CO_2), in association with nitrogen, hydrocarbons, helium and other rare gases forming nonflammable mixtures, is known to occur in Cambrian and/or Devonian rocks penetrated in 14 wells drilled in Saskatchewan. Thirteen of these are in southwestern Saskatchewan south of Twp. 18 W3M, while the fourteenth is located in Twp. 38 Rge. 28 W2M.

The potential for CO_2 production is discussed using these and other geological and seismic data. Flow rate, gas analyses and formation tested for these wells are shown, along with other tests for nonflammable gases from wells in Manitoba, Alberta and Montana.

Maximum recorded CO_2 content of the Saskatchewan inert gases is 83 percent for the Devonian and 1.76 percent for the Cambrian. Generation of CO_2 was probably from the high carbonate content rocks of the Ordovician, Silurian and Devonian penetrated by laccolithic intrusives and volcanics in northern Montana.

Broad regional concepts are used to establish the geological framework and to postulate origin, migration and accumulation of the CO_2-bearing inert gases. Conclusions are based on imperfect data in many cases.

Closed structures, due primarily to draping of Cambrian to Cretaceous sediments over Precambrian erosional hills or monadnocks, which rise as much as 250 m (800 feet) above the regional Precambrian surface, provide the main trapping mechanism. Closures of from 15 to 30 m (50 to 100 feet) seem to persist from the Cambrian through higher formations to at least the Cretaceous. The Cambrian inert gases are trapped in the basal sands over or on the Precambrian hills. The Composite Seismic Map of Southern Saskatchewan on a horizon near the top of the Devonian shows numerous domal structures. Wells in two of these in the Battle Creek - Eastend area have yielded gas from the Devonian occurrences. Potential CO_2 resources of the 30 closed structures in the Battle Creek - Eastend area are estimated. Various risk factors are considered.

Extrapolations are made to estimate reserves from the less potential outlying area.

Total (proven, probable and possible) recoverable CO_2 resources are estimated to be between 28.3 and 56.6 x 10^9 m^3 (1 and 2 trillion cubic feet), of which 2 x 10^9 m^3 (71.4 billion cubic feet) are considered proven.

Some 47.7 to 95.4 x 10^6 m^3 (300 to 600 million barrels) of oil are indicated to be amenable to miscible CO_2 enhanced oil recovery in Mississippian oil fields of southeastern Saskatchewan. Enhanced recovery of 31.8 x 10^6 m^3 (200 million barrels) of oil, or about one-third to two-thirds of the estimated total, could be expected by the utilization of 1 trillion cubic feet of CO_2. The added value is estimated to be $2.25 billion (constant 1986 CAN$) over a period of 20 years based on an oil price of US$20 per barrel.

Other potential subsurface sources of CO_2 are discussed and shown to be located from 145 to

362 km (90 to 225 miles) west of the proven source in the Battle Creek area of Saskatchewan.

Coproduction of some 1.4 x 10^9 m^3 (50 billion cubic feet) of hydrocarbons (mostly methane) would occur along with the production of 1 trillion cubic feet of CO_2.

Coproduction of anhydrous ammonia utilizing the nitrogen and hydrocarbons contained in the inert gas, so as to supply a significant portion of Saskatchewan's requirement for nitrogen fertilizers and other uses, may be economically feasible or become so in the near future.

The possibility of downdip displacement of oil by inert gases into some of the seismically indicated closed structural traps in the area immediately east of the Eastend wells is noted.

Leventhal, J.S., Grauch, R.I., Threlkeld, C.N., Lichte, F.E., and Harper, C.T. (in press): Unusual organic matter associated with uranium from the Claude deposit, Cluff Lake, Canada; Economic Geology, v82, p1169-1176.

Blebs and pods of organic matter (0.2-7.0 cm in diameter) are associated with uranium mineralization in all the major deposits (D, N-R-F, Claude, OP, and Dominique-Peter zones) of the Cluff Lake area in northwestern Saskatchewan. These deposits are hosted in strongly altered quartzofeldspathic, graphitic pelitic, and granitoid gneisses of suspected Archean age and locally, as in the D zone, in the basal section of the unmetamorphosed middle Proterozoic Athabasca Group sediments, which comprise conglomerate, sandstone, and siltstone. Samples of the organic matter from the Claude deposit contain up to 12 percent uranium, principally as small uraninite grains (10-40 µm in diameter) and minor coffinite. Associated mineral grains include pyrite, marcasite, chalcopyrite, galena, molybdenite, jordisite, gersdorffite, and altaite.

The uranium and its daughters have caused massive radiation damage that is expressed as complexly zoned halos approximately 50 um wide in the surrounding organic material. Stable isotope determinations of the bulk organic matter give a $\delta^{13}C$ value of -44 permil vs. PDB, whereas occluded gases CH_4 and CO_2, produced by irradiation, show $\delta^{13}C$ values of -48 and -32 permil vs. PDB, respectively. Pyrolysis-gas chromatography-mass spectrometry of the sample yields mainly one- and fused-ring aromatic molecules from the organic matter that are out of range of the alpha particles from the uraninite grains.

The presence of possible flow structures in the organic matter and the angular nature of the mineral inclusions suggest that most of the minerals were broken from vein walls and mixed into the organic matter as it filled the veins. Thus, their presence in the organic matter is the result of mechanical processes that occurred after the minerals were originally precipitated.

Lewry, J.F. and Thomas, D.J. (1987): A transect across the Trans-Hudson Orogen, La Ronge - Wollaston Lake; Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, Field Trip Guidebook, Trip No. 6, 56p.

Lewry, J.F., Thomas, D.J., Macdonald, R. and Chiarenzelli, J. (1987): Structural relations in accreted terranes of the Trans-Hudson Orogen, Saskatchewan: telescoping in a collisional regime? Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, Saskatoon, May 25-27, 1987, Program with Abstracts, v12, p67.

Structures and strain variation in juvenile terranes of the Trans-Hudson Orogen indicate extreme crustal shortening, fold/thrust stacking and transport of nappe sheets soled by flat-lying high-strain zones. The La Ronge Domain comprises stacked, variably strained northwest/north-dipping tectonostratigraphic packages, bounded by high-strain zones (e.g., MacLennan Lake zone). Parts of the Glennie Domain comprise refolded allochthonous sheets soled by early blastomylonite-tectonic schist zones (e.g., Guncoat and Nistowiak gneisses); the Wapassini Allochthon is continuous with a lower structural level of the La Ronge Domain. Early major folds in much of the Kisseynew Domain were probably initially recumbent or highly overturned. Thus, much of the collage may be a refolded stack of allochthonous sheets, some of major extent, tectonically emplaced in a similar regime as that of arc complexes in the Himalaya. Relations are obscured by later refolding, oversteepening and wrench faulting. The Glennie Domain is an Early Proterozoic arc fragment rather than an Archean block; its low-grade southern part cannot have been deeply buried beneath thrust sheets and may be a independent accreted component. Its relation to the Kisseynew Domain and the nature of the boundary between them (Tabbernor zone) remains uncertain. U-Pb, Nd and Sr isotopic data show that the telescoped complex comprises Early Proterozoic (ca. 1910-1830 Ma) juvenile arcs, derived clastics and later molasse with minor Archean input. Small Archean inliers in the Hanson Lake Block may be refolded slices. Possibly, the complex is now partly underlain by lower plate continental lithosphere emplaced during collision subsequent to arc formation. Seismic investigation and dating/isotopic characterization of late kinematic granites might test this possibility.

Macdonald, R., Sibbald, T.I.I., Thomas, D.J., Slimmon, W.L., Bell, K., Bickerman, M. and Van Schmus, R. (1987): Multiple reactivations in the Trans-Hudson Foreland, Greater Beaverlodge area, northwestern Saskatchewan; Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, Saskatoon, May 25-27, 1987, Program with Abstracts, v12, p69.

The Greater Beaverlodge area lies within an approximately 50 km radius of Uranium City, and is part of the northwestern foreland of the Trans-Hudson Orogen in Saskatchewan. The area was studied in detail during the fifties and sixties, and since 1980 has been the subject of remapping, compilation and further geochronological work.

This synthesis attempts to show the development of the region in terms of successive reactivations (and possible reassembly) of Archean crust, commencing with the Lodge Bay Granite - an apparently isolated remnant recently dated at ca. 3060 Ma. These reactivations include tectonometamorphic events at ca. 2500 and 2200 Ma, anatectic magmatism at ca. 2600 Ma, and distinctive metasomatic magmatism at 2350 Ma followed by retrogression and albitization in auriferous granites at ca. 2000 Ma. The Murmac Bay Group, a shelf-type sequence of quartzites, dolomites, iron-formation, mafic flows and ultramafic rocks, directly overlies the Lodge Bay Granite and was variously involved in at least the last two of these events. There are lateral variations in tectonic style and metamorphic grade (ranging from greenschist to granulite facies), as well as in overprint. Progressively developed mylonitic shearing to microbrecciation (host in places to uranium mineralization) eventually defined broad graben zones at ca. 1795 Ma, largely infilled with sediments, most of which are postmetamorphic. This history appears to show some diachronism with the Alberta part of the foreland and with the Proterozoic arcs of the Trans-Hudson Orogen to the south.

Pearson, J.G. (1987): Gold mineralization in the Flin Flon - Amisk Lake area, Saskatchewan; in Gilboy, C.F. and Vigrass, L.W. (eds.), Economic Minerals of Saskatchewan; Saskatchewan Geological Society, Special Publication 8, p37-43.

The distribution of gold occurrences in the Flin Flon and Amisk Lake areas indicates a stratigraphic or structural control governing the localization of these deposits. In the Flin Flon area, two generations of gold mineralization are recognized. The early-generation deposits are narrow (less than one metre wide) quartz-sulphide veins that occupy minor northwesterly trending fractures in basalt; these fractures apparently originated during the second recognizable regional deformation (P2) to have affected the host rocks. The late-generation deposits occupy fractures (which formed during the third regionally developed tectonism, P3) around or within the Phantom Lake Pluton in the following settings:

1) quartz veins in intensely carbonatized basalt,

2) multiple generations of quartz veining with attendant porphyry-style alteration in the Boot Lake Pluton, and

3) foliated chlorite-carbonate-sericite rock with boudinaged quartz veins in the Phantom Lake Pluton.

This late style of mineralization and associated alteration appears to be consistent with that generated by a fracture-controlled porphyry system.

In the Amisk Lake area, two types of gold occurrence are recognized:

1) gold-quartz-carbonate-sulphide veins within or flanking fault zones, and

2) structurally and stratigraphically controlled zones of disseminated and vein-type sulphide-gold mineralization within extrusive and intrusive rhyolite porphyries.

Both types of deposit lie within supracrustal rocks, are accompanied by intense alteration haloes, and were formed prior to the major deformation event, P2 (thus suggesting their early epigenetic hydrothermal origin).

Saskatchewan Geological Survey (1987): Saskatchewan's mineral industry: past and present; CIM Bulletin, Annual Review, Vol. 21.

Saskatchewan is effectively divided into a northern setting of deformed Precambrian basement and undeformed Athabasca sedimentary rocks, and a southern region of sedimentary strata ranging from Cambrian to Tertiary. This dichotomy determines the distribution of mineral industry and related government activities. Thus, the metallic mineral environment is northern and the nonmetallics, as well as petroleum and natural gas, are southern. Saskatchewan is endowed with inland oil reserves second only to Alberta's, natural gas third to British Columbia's, potash, sodium sulphate and uranium second to none in Canada, and significant coal reserves. These resources support industries

made up of companies ranging from the internationals to self-incorporated individuals.

The gold play has come to Saskatchewan, as it has elsewhere. Deposits which have lain undeveloped for 50 years and more because of small size are now the focus of intense exploration and evaluation. The drive to develop this resource and find new deposits has been propelled by a combination of prospecting perseverence, investment flow-through funding and favourable economics. An additional stimulant has been the focussed mapping program delivered by the Saskatchewan Geological Survey and the Geological Survey of Canada, working together under the Canada-Saskatchewan Mineral Development Agreement. Gold prospecting, promotion and development share many similarities with counterpart activities in the petroleum sector of the south. At their peak, they are each dominated by more than 100 small companies pursuing smaller prospects and returns under the umbrella of a few larger companies looking for the big strike.

The value of mineral sales approached $3.6 billion dollars in 1985, of which petroleum and natural gas contributed $2.21 billion, potash $621 million, uranium $456 million, coal $86.5 million and sodium sulphate $30.2 million. With respect to the provincial economy, the mineral industry represents 12.5 percent of the provincial Gross Domestic Product, or the same as agriculture (Saskatchewan Bureau of Statistics, 1986).

This paper provides overviews of (a) the progress of mineral exploration from the early years to the present, (b) the geology of the province as a backdrop to the mineral industry, and (c) the current status of the industry in its various components. Emphasis is on the metallic and industrial minerals, although petroleum forms part of the historical review.

Contributors to this paper are as follows:

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T.I.I. Sibbald, Metallic Minerals

Scott, B.P. and Slimmon, W.L. (1986): Compilation bedrock geology, Lloyd Lake, NTS area 74F; Saskatchewan Energy and Mines, Report 231 (1:250,000 scale map with marginal notes).

Scott, B.P. (1986): Metallogenic map series, Foster Lake, NTS area 74A; Saskatchewan Energy and Mines, Report 252 (1:250,000 scale map with marginal notes).

Sibbald, T.I.I. (1987): Geology and genesis of the Athabasca Basin uranium deposits; unpublished paper presented at International Atomic Energy Agency, Technical Committee Meeting on Uranium Resources and Geology of North America, August 31 to September 4, 1987.

The Athabasca Basin contains a 1400 m thick redbed succession, the Athabasca Group of Paleohelikian (ca. 1450 Ma) age, and occupies an area of some 100,000 km^2. Fluviatile quartz sandstones and conglomerates give way upward to finer marine clastics and these in turn to stromatolitic and oolitic dolomite. Cross-cutting northwesterly trending diabase dykes are dated at between 938 and 1230 Ma.

The Athabasca Group is underlain by a lateritic weathering profile in crystalline basement rocks belonging to two major subdivisions of the Saskatchewan Shield, the Cree Lake (Mobile) Zone and Western Craton. These are separated by a major shear zone, within a zone of low gravity which is locally intruded by Hudsonian (ca. 1750 Ma) uranium enriched 'granite'. The Cree Lake high-grade metamorphic zone comprises Lower Proterozoic shelf-type supracrustals (Wollaston Group) overlying predominantly granitoid basement, which was variably remobilized into gneiss domes and recumbent gneiss lobes during Hudsonian (sensu lato) orogenesis. In part, the supracrustals have become incorporated in the granitoid infrastructure. The Western Craton shows similar ages of rocks, but on a large scale has suffered plastic rather than ductile deformation, with the development of geologically complex zones of Hudsonian (sensu lato) reworking surrounding Archean granulite facies cratonic nuclei.

Recognizable controls of Athabasca Basin uranium mineralization are a) the sub-Athabasca Group unconformity, b) fracturing and faulting, and c) graphite in basement rocks. The deposits exhibit, to varying degrees, complex mineralogy and geochemistry (U $\pm$ Ni, Co, As, Cu, Pb, Zn, Ag, Au, Pt group elements, Mo, V, Se, Mn and Fe). They are surrounded by extensive argillic alteration haloes in the Athabasca Group and more restricted haloes in the basement. Redox relationships are characteristic of most deposits. Dating of pitchblende and alteration minerals suggests epigenetic emplacement beginning 1350 Ma ago. Fluid inclusion studies indicate deposition from saline mineralizing fluids at temperatures between 150 and 225°C.

The most acceptable model of deposit genesis, the diagenetic-hydrothermal model, involves interaction

of hot, oxidized, metalliferous formational waters of the Athabasca Group with the underlying 'reduced' basement. Mineralization was episodic and likely triggered by tectonic events, possibly related to diabase dyke emplacement and/or uplift. The model requires neither local repeated enrichment by diverse processes throughout earth history, nor the existence of a specialized, uranium-enriched source.

Sibbald, T.I.I. (1987): Overview of the Precambrian geology and aspects of the metallogenesis of northern Saskatchewan; in Gilboy, C.F. and Vigrass, L.W. (eds.), Economic Minerals of Saskatchewan; Saskatchewan Geological Society, Special Publication 8, p1-16.

This paper provides a broad overview of the geology of the Precambrian Shield of northern Saskatchewan and particularly emphasizes the results of recent radiometric age-dating work. It also focuses on aspects of the region's metallogenesis.

On a province-wide scale, three major geological subdivisions are identified:

1) an ensimatic regime made up of the Southeastern Complex and the La Ronge - Rottenstone Magmatic Belt,

2) an ensialic regime represented by the Cree Lake Ensialic Mobile Zone and the Western Craton, and

3) the Athabasca Basin, filled by unmetamorphosed, predominantly coarse fluvial and marine clastic rocks which unconformably overlie crystalline basement.

Lower Proterozoic metallogenesis reflects the contrasting ensimatic and ensialic regimes. Volcanogenic base - metal and gold mineralization typifies the eugeoclinal volcanic-plutonic arc and interarc sequences of the former; sedimentogenic base - metal and uranium mineralization is characteristic of the miogeoclinal sequences which overlie the Archean basement in the latter. Reference is made to a major Hudsonian crustal feature which transects the Western Craton. It is characterized by high radiometric and low gravity signatures, and may have potential for granite-hosted tin-tungsten mineralization. The rich, economically important, unconformity-type uranium deposits of the Middle Proterozoic Athabasca Basin are described, as also are aspects of the diagenetic-hydrothermal model proposed for their formation. The question is raised as to whether the Basin also has potential to host economic concentrations of any of the diverse suite of elements typically associated with the uranium mineralization.

Northern Saskatchewan's various "gold camps" are identified, and their geology briefly examined. Historical gold exploration figures for Saskatchewan are contrasted with those of the established gold provinces of Quebec and Ontario. They seem to suggest that, to date, Saskatchewan has been relatively little explored and that the province's gold potential has yet to be fully realized.

Sibbald, T.I.I. and Quirt, D.H. (1987): Uranium deposits of the Athabasca Basin; Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, Field Trip Guidebook, Trip No. 9, 72p.

Sibbald, T.I.I., Rees, M.I. and Quirt, D.H. (1987): Geology of the gold deposits, Goldfields, Saskatchewan; Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, Saskatoon, May 25-27, 1987, Program with Abstracts, v12, p88.

The Goldfields area on the north shore of Lake Athabasca was the scene of a significant gold rush in the thirties. Between 1939 and 1942, 64,066 oz. of gold were extracted underground from the Consolidated Mining and Smelting Company of Canada Ltd.'s Box Mine.

Supracrustal rocks intruded by mafic bodies and invaded by 'granite' underlie the area. The supracrustals, of Lower Proterozoic age, are characterized by a shelf succession dominated by quartzites and metamorphosed to lower to middle amphibolite facies. The 'granitic' rocks are of replacement, metasomatic type. Two major deformation events are recognized. The early penetrative event was accompanied and outlasted by prograde metamorphism, whereas the later event, which gave rise to the major upright Goldfields synform, was typified by retrograde metamorphism.

Gold mineralization occurs within discrete lenticular bodies of leucocratic homogeneous 'granite' characterized by disseminated sulphides and cut by stockworks of quartz veins. Gold, typically associated with pyrite±sphalerite± galena±chalcopyrite, occurs primarily in the quartz veins but is also present in the wall rocks. It is found free, in pyrite and as coatings on microfractures. Geochemically, the mineralization is simple and expressed by Au±Ag±Zn±Pb±Cu and Mo. Adjacent to veins, wallrock alteration is neither megascopically nor microscopically apparent, although regional retrograde metamorphism, in part associated with extensive albitization, accompanied quartz veining. Various hypotheses for the origin of this enigmatic type of gold mineralization will be examined in the context of available petrological, geochemical, geochronological, fluid inclusion and stable isotope data.

Slimmon, W.L. (1986): Lloyd Lake (NTS 74A) geological bibliography; Saskatchewan Energy and Mines, Data File 11, 6p.

Thomas, D.J. (1987): Gold deposits of the La Ronge Domain; Geological Association of Canada/ Mineralogical Association of Canada, Joint Annual Meeting, Field Trip Guidebook, Trip No. 4, 70p.

Thomas, D.J. and Harper, C.T. (1987): Review of a Lower Proterozoic gold belt from northern Saskatchewan; Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, May 25-27, 1987, Program with Abstracts, v12, p95.

The "La Ronge Gold Belt" is composed of volcanosedimentary-plutonic rocks of the La Ronge and Glennie Lake Domains which form part of an accretionary oceanic island arc complex within the Lower Proterozoic "Trans-Hudson Orogen". There are more than 80 gold occurrences in this region, the majority being classified as structurally controlled quartz vein-type, with minor stratabound type and volcanogenic epithermal type. Structural controls include, in order of importance, early high-temperature ductile shears (e.g., Star Lake and Laonil Lake), fracture systems developed at pluton margins (e.g., Komis deposit) and late, low-temperature brittle fractures (e.g., Tower Lake). Stratabound occurrences are commonly associated with mixed facies iron formation (e.g., Wedge Lake), base metal elevated massive sulphides (e.g., Churchill Minerals) and carbonaceous-sulphidic metasediments within felsic volcanic sequences (e.g., Sulphide Lake). Volcanogenic, silver-dominated epithermal precious metal occurrences (e.g., Jojay showing) are associated with quartz stringer zones in felsic volcanics.

The dogma that Lower Proterozoic greenstone belts have a lower potential for gold than their Archean equivalents can possibly be refuted in the light of similarities in controls of mineralization as well as comparable cost effectiveness of exploration in these younger terrains. This presentation will review the principal features of the main gold camps and identify regional metallogenic models within the geological framework of the "La Ronge Gold Belt".

Thomas, D.J. and Sibbald, T.I.I. (1987): The Lower Proterozoic La Ronge Gold Belt; unpublished paper presented at Prospectors and Developers Association of Canada, Annual Convention, Toronto, March 8-11, 1987.

This presentation will review recent gold exploration and deposit developments in the "La Ronge Gold Belt" of northern Saskatchewan. Particular examples of recent discoveries include the Star Lake Mine, which will be operating by late 1986, and the Rod deposit at Mallard Lake where an exploration decline is presently being driven. The presentation will briefly review the principal geological features of the main gold camps at Waddy - Tower Lakes, Star Lake, Sulphide Lake and Laonil Lake. Common characteristics will be identified and placed within the regional geological framework to establish criteria for grassroots exploration.

The Saskatchewan Shield between La Ronge - Pelican Narrows - Southend (Reindeer Lake) has been loosely termed the "La Ronge Gold Belt". It is underlain by Lower Proterozoic volcanosedimentary-plutonic sequences of the La Ronge and Glennie Lake Domains. The majority of gold occurrences are found in the La Ronge Domain, and more specifically within a region of weakly deformed and metamorphosed volcanic and plutonic rocks referred to as the Central Metavolcanic Belt. Recent detailed geological mapping and lithogeochemical studies of the metavolcanic and plutonic components in this belt strongly supports an oceanic island-arc setting. The Glennie Lake Domain is interpreted as a fragmented arc which has collided with the La Ronge Domain.

The majority of the more than 80 gold occurrences in the "La Ronge Gold Belt" are classified as structurally controlled quartz vein-type (about 80 percent), while the remainder are broadly referred to as stratabound deposits (about 20 percent). Regionally, about 50 percent are hosted by intrusive rocks, 30 percent by metavolcanic rocks and 20 percent by metasedimentary rocks. Most of the occurrences are controlled by small, high-temperature, ductile shear zones, although some appear related to fracture systems developed at pluton margins and others to major 'late' (low-temperature) faults. The less abundant stratabound occurrences are commonly associated with iron formations within felsic volcanic sequences. The main gold camps in the "La Ronge Gold Belt" are all characterized by mafic to felsic metavolcanic-volcaniclastic piles with intercalated metasediments, intruded by composite or multiphase synvolcanic to posttectonic bodies of gabbroic to granitic composition.

Estimated gold exploration expenditure in Saskatchewan, principally in the La Ronge Gold Belt, between 1946 and 1984 is $29 million (in constant 1985 dollars), with an additional $25 million being spent since 1984. Exploration to 1984 has yielded some 1.5 million ounces gold at an exploration cost of $19 per ounce. Comparable exploration costs for Quebec and Ontario are $23 per ounce and $15 per ounce respectively ($43 per ounce excluding Hemlo), demonstrating that the exploration dollar has been as effective in Saskatchewan as in central Canada. Translated into geological terms, these figures refute the dogma that Lower Proterozoic greenstone

belts have a lower potential than their Archean equivalents. In that the geological controls of mineralization appear to be similar in both environments, such a conclusion is not overly surprising.

Thomas, D.J. and Watters, B.R. (1987): The Star Lake Pluton and its gold mineralization - an overview; in Gilboy, C.F. and Vigrass, L.W. (eds.), Economic Minerals of Saskatchewan; Saskatchewan Geological Society, Special Publication 8, p54-57.

The Star Lake Pluton is a calc-alkaline pretectonic composite intrusion emplaced into a Lower Proterozoic oceanic island arc volcanosedimentary sequence in northern Saskatchewan. Upper greenschist to lower amphibolite grade metamorphism related to Hudsonian thermotectonism has affected the intrusion and its supracrustal envelope. The pluton displays a marked concentric zonation of rock types ranging from a gabbro-diorite marginal phase, through a monzonite-granodiorite-quartz monzonite transitional phase, to a granite central phase. Geochemical variation diagrams display almost linear interelement trends which exhibit increasing SiO_2, K_2O, Na_2O and decreasing FeO and MgO contents from the marginal to the central zones of the intrusion. A progressive decrease in total REE contents from the margin to the centre of the body is attributed primarily to the involvement of amphibole in the evolution of the magmas. The Star Lake Pluton is interpreted as an I-type felsic intrusion generated by partial melting of meta-igneous rocks in the roots of an island arc.

The pluton is intruded by northeasterly trending dyke swarms ranging in composition from ultramafic and mafic through intermediate to felsic. Northeast-trending ductile shear zones which deform the pluton are commonly centred along these dykes. The dykes may have acted as zones of weakness along which the shear strain was most easily accommodated. Gold-bearing pyritic and pyrrhotitic quartz veins within the shear zones are prevalent throughout the intrusion, and are considered to have been emplaced contemporaneously with shearing as a single progressive 'crack and seal' event.

One shear-controlled vein containing 210,000 tonnes at 17.0 g/t Au is presently being exploited at the Star Lake Mine. The Rod Zone, which has drill-indicated reserves of 810,000 tonnes at 20.9 g/t Au, is presently awaiting an underground exploration phase.

Thomas, D.J., Watters, B.R. and Harper, C.T. (1987): The character of Early Proterozoic plutonism in the Central Metavolcanic Belt, northern Saskatchewan; Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, Saskatoon, May 25-27, 1987, Program with Abstracts, v12, p95.

The Central Metavolcanic Belt (CMB) is an Early Proterozoic volcanosedimentary-plutonic sequence which comprises one part of the Rottenstone - La Ronge Magmatic Belt of the Trans-Hudson Orogen. U-Pb zircon dating indicates that major volcanism in the CMB occurred between 1885 and 1875 Ma ago and major plutonism between 1870 and 1830 Ma ago. On the basis of lithology, field relationships and geochronology, a broad subdivision of plutonic rocks in the CMB is made. These are: a) an 'early', possibly synvolcanic, episode (Type 1) marked by composite intrusions ranging from gabbro-diorite to granite; b) an 'intermediate' plutonic event (Type 2) distinguished by homogeneous felsic intrusions; and c) a 'later' event (Type 3) characterized by leucocratic quartz-rich granite intrusions. Geochemical variation diagrams of plutonic rocks from the belt display a strong calc-alkaline character for the majority of intrusions, while minor and trace element discrimination plots and Sr isotope data suggest a volcanic arc tectonic setting of emplacement. This is consistent with the tectonic setting inferred for the volcanosedimentary sequence of the CMB.

The distinguishing lithological, structural and geochemical characteristics of the three intrusive types identified in the CMB will be reviewed. The Star Lake and Island Lake Plutons will be described in detail, as they provide a good example of the spatial and temporal relationship between a Type 1 and Type 2 intrusion respectively. Partial melting and fractional crystallization evolutionary models are discussed, specifically with respect to the Star Lake and Island Lake intrusions, as well as to plutonism in the CMB in general.

Watters, B.R., Thomas, D.J. and Harper, C.T. (1987): Tectonic setting of Early Proterozoic volcanism of the Domain, northern Saskatchewan; Geological Association of Canada/Mineralogical Association of Canada, Joint Annual La Ronge Meeting, May 25-27, 1987, Program with Abstracts, v12, p100.

The Central Metavolcanic Belt of the La Ronge Domain, in the Trans-Hudson Orogen, comprises complex assemblages of Early Proterozoic lava flows, volcaniclastic units and minor sedimentary rocks, invaded by plutons of mainly Hudsonian age.

Diverse subaqueous and subaerial primary volcanic features are well preserved in much of the belt and suggest development in a volcanic arc environment. Such an interpretation is supported by geochemistry. The metavolcanics range from basalt through andesite to rhyolite in composition, and calc-alkaline and tholeiitic types are dominant. Trace element characteristics of the basalts are particularly distinctive in providing tectonic characterization; MORB-normalized geochemical patterns display enrichment in incompatible elements of low ionic potential and depletion in elements of high ionic potential. The calc-alkaline basalts are also enriched in Th, P, Ce and Sm. REE patterns show enrichment in the LREE with little or no Eu anomaly.

Lithological and chemical changes along the strike of the belt define regional variations in the tectonic setting, from a dominant oceanic island arc type to a transitional or continental margin volcanic arc environment.

Wilson, M.A. and Bennett, R.W. (1986): Heavy Oil Project; Saskatchewan Energy and Mines, 29 net pay maps at 1:250,000 scale, 4 sheets of detailed net pay maps at 1:100,000 and 4 sheets of cross-sections.

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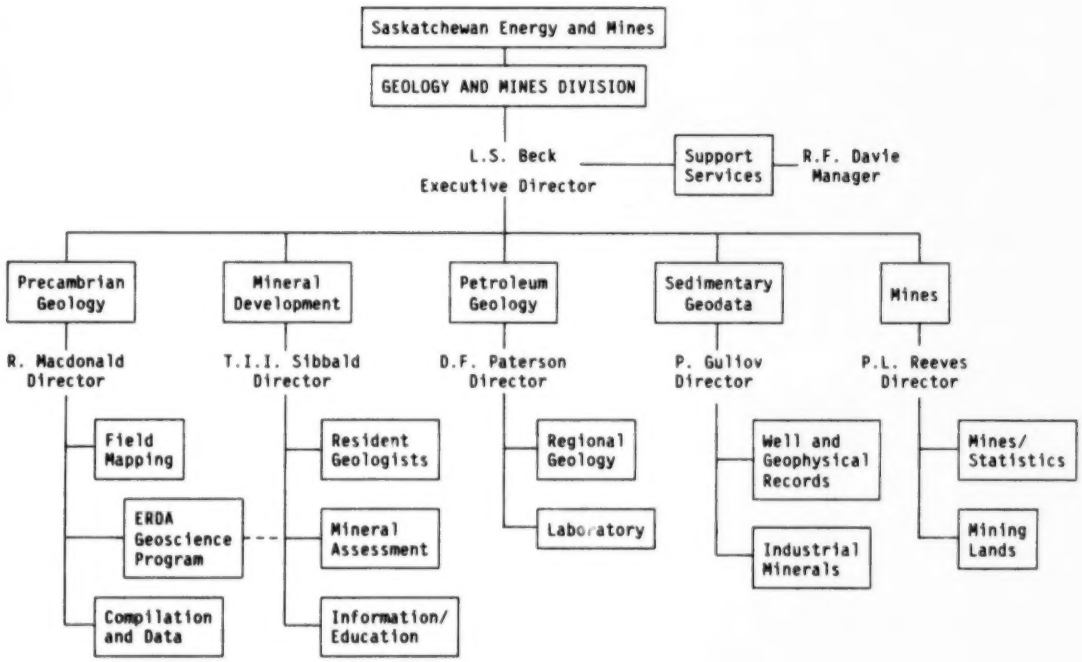

The Saskatchewan Geological Survey comprises the geoscience activities of the Precambrian Geology, Mineral Development, Petroleum Geology and Sedimentary Geodata branches.

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Draftspersons ..... P.A. Weir
K.G. Jones

General Drafting Unit:
Supervisor ..... J.J. Bedo
Draftspersons ..... R.O. Pearce
J.E. Sloat
A.H. Buyze[4]

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[1]position contracted under ERDA Mineral Development Agreement
[2]also serving Mineral Development Branch
[3]consultant
[4]temporary

MAPS NOT

FILMED

CARTES

OMISES